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APTI (Air Pollution Training Institute) Course 450 Source Sampling for Particulate Pollutants. Student Workbook

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Course 450
Source Sampling for Particulate Pollutants

Student Workbook

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16. ABSTRACT

This workbook is used in conjunction with Course #450, "Source Sampling for Particulate Pollutants", as designed and presented by the EPA Air Pollution Training Institute (APTI). The workbook includes course objectives, lecture aides, calculation problems, and instructions for the course laboratory exercises. Tables of nomenclature, source sampling forms, and representations of selected course visual materials are given to aide the student in his understanding of EPA Federal reference method 5 for sampling particulate matter from stationary sources. The workbook is not meant to stand on its own, but is to be used with the course manual, EPA-450/2-79-006 during the lecture and laboratory sessions of the training course. An instructor's manual (EPA 450/2-80-003) entitled "Source Sampling for Particulate Pollutants" is also available for use in presenting the training course.

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United States Environmental Protection Agency
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AIR POLLUTION TRAINING INSTITUTE
MANPOWER AND TECHNICAL INFORMATION BRANCH
CONTROL PROGRAMS DEVELOPMENT DIVISION
OFFICE OF AIR QUALITY PLANNING AND STANDARDS

The Air Pollution Training Institute (1) conducts training for personnel working on the development and improvement of state, and local governmental, and EPA air pollution control programs, as well as for personnel in industry and academic institutions; (2) provides consultation and other training assistance to governmental agencies, educational institutions, industrial organizations, and others engaged in air pollution training activities; and (3) promotes the development and improvement of air pollution training programs in educational institutions and state, regional, and local governmental air pollution control agencies. Much of the program is now conducted by an on-site contractor, Northrop Services, Inc.

One of the principal mechanisms utilized to meet the Institute's goals is the intensive short term technical training course. A full-time professional staff is responsible for the design, development, and presentation of these courses. In addition the services of scientists, engineers, and specialists from other EPA programs, governmental agencies, industries, and universities are used to augment and reinforce the Institute staff in the development and presentation of technical material.

Individual course objectives and desired learning outcomes are delineated to meet specific program needs through training. Subject matter areas covered include air pollution source studies, atmospheric dispersion, and air quality management. These courses are presented in the Institute's resident classrooms and laboratories and at various field locations.

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Major Course Goals

The major goal of Course #450, "Source Sampling for Particulate Pollutants", is to provide the student with a basic understanding of the theory and experimental methods involved in isokinetic sampling, the foundation of EPA Method 5.

Knowledge of isokinetic sampling, serving as the core of the course material, will then be amplified with lectures, problem sessions and lecture-demonstrations in order to present the many facets of particulate sampling. Upon completion of the course, the student should be able to design and plan a source test, perform all of the calculations involved in reporting a mass emission rate, and understand problems of error and quality assurance. The student should also become conversant with the methods of particle sizing and transmissometry. He should attain an awareness of the problems involved in source sampling and be able to recognize what constitutes difficult experimental situations, a good test, good data, and a good final report.

Course Objectives

On completion of this course the student should be able to:

- Define symbols and common source sampling terms used in source sampling for particulate pollutants.
- Recognize, interpret and apply sections of the *Federal Register* pertinent to source sampling for particulate pollutants.
- Understand the construction, operation and calibration of component parts of the *Federal Register* Method 5 sampling train.
- Recognize the advantages and disadvantages of the nomograph and its uses in the establishment of the isokinetic sampling rate.
- Understand the "working" isokinetic rate equation and its derivation.
- Define isokinetic sampling and illustrate why it is important in sample extraction.
- Apply *Federal Register* Methods 1 through 4 in preparation for a particulate sampling test.
- Understand the construction, evaluation, standardization and orientation of the "S Type" pitot tube and its application to source sampling.
- Calculate the "Percent Isokinetic" value for a source test, and interpret the effect of over or under—isokinetic values on the source test results.
- Understand the quality assurance programs involved in source sampling dealing with nozzle sizing, orifice meter calibration, nomograph standardization and sample recovery.
- List the steps involved in conducting a source test, including completion of pre-test and post-test forms. The student should be able to recognize potential problem areas in preparing and conducting a source test.
- Properly assemble, leak check, conduct and recover a Method 5 sample according to *Federal Register*, August 18, 1977.
- Apply *Federal Register* Method 3 gas analysis in formulating the stack gas molecular weight and % excess air.
- Explain the principles behind the operation of particles sizing devices for sources and name some of those devices being tested by EPA.
- Define the terms opacity, transmittance and transmissometer.
- Recognize the relationship between optical density and particulate concentration.

Introduction

The determination of particulate emissions from a stationary source requires the measurement of several source variables. The stack gas emitted from an incineration or process stack is a mixture of a number of gas components and particulates. The temperature and moisture content of the gases vary from source to source. The volume of gases emitted varies according to the size and type of the plant. It is not possible to sample all the gases and particulates emitted from a source in a given time period, therefore, a system was developed that would extract a representative sample while monitoring pertinent stack variables. The data from this representative sample is used in calculating an average particulate concentration in the stack gas. This concentration is calculated on the basis of standard gas temperature and pressure. The data are then utilized in calculating the emissions in terms of lbs/10^6 Btu Heat Input.

The Air Pollution Training Institute has developed Course 450 to instruct engineers, chemists, and technicians in particulate sampling methods. The sampling techniques and calculations used in the EPA Method 5 source sampling system are demonstrated and practiced for student comprehension. Students completing the 450 course with an understanding of the lecture, laboratory, and text materials should be able to conduct a Method 5 particulate determination at a stationary source.

This workbook is designed to provide the student with a guide to the lecture materials and laboratory exercises. Incorporated in this workbook the student will find reproductions of selected visual materials, lecture problems and data reporting forms. Lecture and laboratory sessions are presented in order of their expected presentation. Space is provided for additional notation by the student of lecture material as presented by the instructor.

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Lecture 1

WELCOME, REGISTRATION AND PRETEST

Lesson Objectives:

- To allow students to introduce themselves to the class; to determine the actual level of job experience in the class (the number of stack tests in which each student has participated) and to complete the pretest.

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Lecture 2

INTRODUCTION TO SOURCE SAMPLING

Lesson Objectives:

The student will be able to:

- Locate the goals and objectives of the course.
- Define the symbols and common source sampling terms used in the course.
- Recognize the basic features of the EPA Method 5 sampling train.
- Write the expressions for pollutant mass rate and emission rate, using symbols for stack gas concentration, stack gas volumetric flowrate, and heat-input rate.
- Recognize the pitot tube equation on sight and understand the relative importance of the parameters in the equation.
- Write the ideal gas law equation and be able to describe the effects of changing pressure and temperature on a gas volume.
- Recognize the form of an ideal gas law correction equation.
- Recognize the importance of Bernoulli's principle in source sampling.

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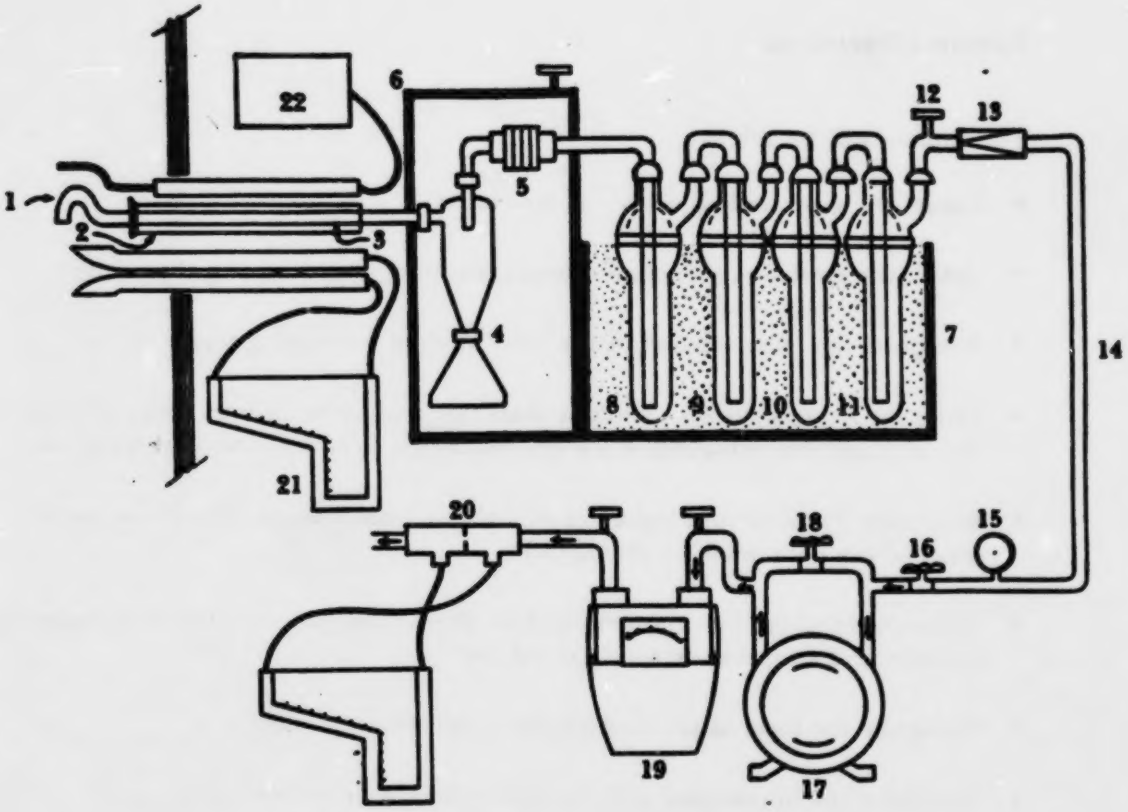


EPA Method 5 particulate sampling train

Nomenclature

A_n – sampling nozzle cross-sectional area

A_s – stack cross-sectional area

a – mean particle projected area

B_{wm} – percent moisture present in gas at meter

B_{ws} – percent moisture present in stack gas

C_p – pitot tube calibration coefficient

$C_{p(std)}$ – standard pitot-static tube calibration coefficient

c_s – particulate concentration in stack gas mass/volume

c_{ws} – particulate concentration on a wet basis mass/wet volume

$c_{s_{12}}$ – particulate concentration corrected to 12% CO_2

$c_{s_{50}}$ – particulate concentration corrected to 50% excess air

D_E – equivalent diameter

D_H – hydraulic diameter

D_n – source sampling nozzle diameter

E – emission rate mass/heat Btu input

e – base of natural logarithms ($\ln 10 = 2.302585$)

%EA – percent excess air

F_c – F-factor using c_s and CO_2 on wet or dry basis

F_d – F-factor using c_s and O_2 on a dry basis

F_w – F-factor using c_{ws} and O_2 on a wet basis

F_o – miscellaneous F-factor for checking orsat data

$\Delta H_@$ – pressure drop across orifice meter for 0.75 CFM flow rate at standard conditions

ΔH – pressure drop across orifice meter

j – equal area centroid

K_p – pitot tube equation dimensional constant

$$\text{Metric Units} \quad 34.97\ \text{m/sec.} \left[\frac{\text{g/g mole (mm Hg)}}{(^\circ\text{K})(\text{mm } H_2O)}\right]^{1/2}$$

$$\text{English Units} = 85.49\ \text{ft./sec.} \left[\frac{\text{lb/lb mole(in. Hg)}}{(^\circ\text{R})(\text{in. } H_2O)}\right]^{1/2}$$

L — length of duct cross-section at sampling site
ℓ — path length
L_1 — plume exit diameter
L_2 — stack diameter
m — mass
M_d — dry stack gas molecular weight
M_s — wet stack gas molecular weight
n — number of particles
N_{Re} — Reynolds number
O_1 — plume opacity at exit
O_2 — in stack plume opacity
P_{atm} — atmospheric pressure
P_b — barometric pressure ($P_b = P_{atm}$)
P_m — absolute pressure at the meter
pmr — Pollutant mass rate
P_s — absolute pressure in the stack
P_{std} — standard absolute pressure
Metric Units = 760 mm Hg
English Units = 29.92 in. Hg
Δp — gas velocity pressure
$\Delta p_{(std)}$ — standard velocity pressure read by the standard pitot tube
Δp_{test} — gas velocity pressure read by the type "S" pitot tube
q — particle extinction coefficient
Q_s — stack gas volumetric flow rate corrected to standard conditions
R — Gas law constant, $21.83 \frac{(\text{in. Hg})(\text{ft.}^3)}{(\text{lb} - \text{mole})(°\text{R})}$
t — temperature (°Fahrenheit or °Celsius)
T_m — absolute temperature at the meter
Metric Units = °C + 273 = °K
English Units = °F + 460 = °R
T_s — absolute temperature of stack gas
T_{std} standard absolute temperature
Metric Units = °20°C + 273 = 293°K
English Units = 68°F + 460 = 528°R
V_m — volume metered at actual conditions
$V_{m_{std}}$ — volume metered corrected to standard conditions
v.p. — water vapor pressure
v_s — stack gas velocity
Volume H_2O — Metric units = 0.00134 m^3/ml × ml H_2O
English units = 0.0472 $ft.^3$/ml × ml H_2O
W — width of the duct cross-section at the sampling site
θ — time in minutes

Subscripts

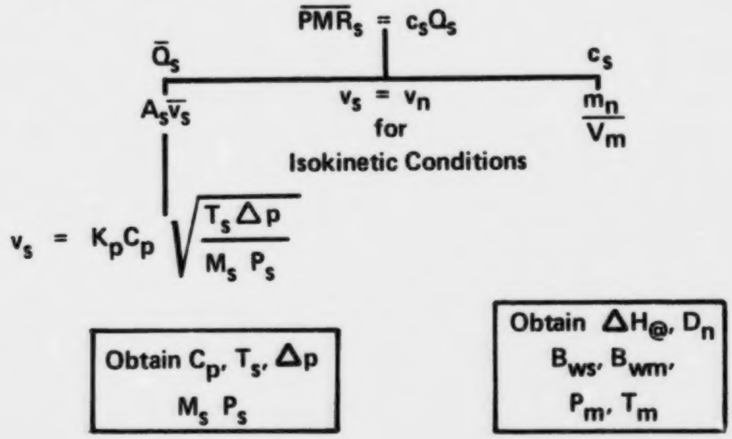
atm — atmospheric
ave — average
b — barometric
d — dry gas basis
f — final
g — gage
i — initial
m — at meter
n — at nozzle
p — of pitot tube
s — at stack
SCF — standard cubic feet
std — standard conditions
w — wet basis

NOTES:

III. EMISSION RATE

Methods of monitoring source emissions

POLLUTANT MASS RATE


$\overline{PMR}_s = c_s Q_s$
$\bar{Q}_s$
c_s
$A_s \bar{v}_s$
$v_s = v_n$
for
Isokinetic Conditions
$\frac{m_n}{V_m}$
$v_s = K_p C_p \sqrt{\frac{T_s \Delta p}{M_s P_s}}$
Obtain C_p, T_s, Δp
M_s P_s
Obtain $\Delta H_@$, D_n
B_{ws}, B_{wm},
P_m, T_m

$$V_{nozzle} = V_{stack}$$

ISOKINETIC CONDITION

$$v_s = K_p C_p \sqrt{\frac{T_s \, \Delta p}{M_s \; P_s}}$$

PITOT TUBE EQUATION

Emissions in terms of
lbs / 10^6 Btu heat input

$$E = \frac{c_s \, \bar{Q}_s}{\bar{Q}_H}$$

GAS PHYSICS
Ideal Gas Law

Volume Correction

$$V_{s_{corr}} = V_s \frac{P_s\ T_{std}}{P_{std}\ T_s}$$

Bernoulli's Principle

$$\frac{1}{2} m \triangle v^2 + mg\triangle h + V\triangle p = 0$$

Lecture 3

EPA METHOD 5 SAMPLING TRAIN

Lesson Objectives:

The student will be able to:

- List the construction and calibration requirements for the Method 5 Sampling Nozzle.
- List the nozzle, probe, pitot tube, and thermocouple placement requirements to minimize aerodynamic interferences.
- List the approved construction materials for the nozzle probe, pitot tube, and probe liner.
- Describe the probe locking system for preventing misalignment in the gas stream.
- Describe the advantages and disadvantages of various types of sample cases and glassware.
- List the advantages and disadvantages of various materials used in constructing umbilical lines.
- Describe the advantages of magnehelic gages for pressure measurements and list the requirements for using these gages in an EPA Method 5 Sampling System.
- Compare the cost effectiveness of the nomograph and calculator.

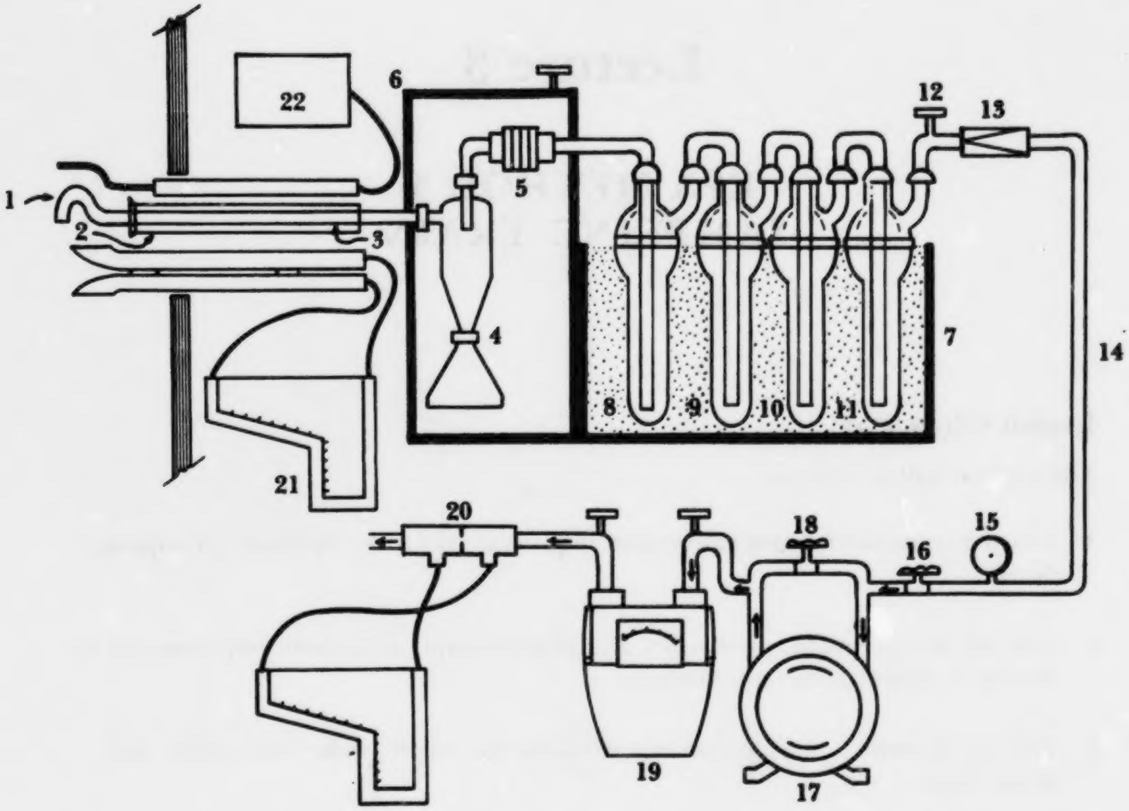


Figure 3-1. EPA Method 5 particulate sampling train

1. Sampling nozzle
2. Sampling probe sheath
3. Heated sample probe liner
4. Cyclone assembly (proposed regulations do not require this cyclone)
5. Out of stack filter assembly
6. Heated filter compartment maintained 120°C ± 14°C (248°F ± 25°F) (or temperature specified in 40CFR subpart)
7. Impinger case
8. First impinger filled with H_2O (100 ml)
9. Greenburg-Smith (or modified Greenburg-Smith) impinger filled with H_2O (100 ml)
10. Third impinger—dry
11. Fourth impinger—filled with H_2O absorption media (200-300 gm)
12. Impinger exit gas thermometer
13. Check valve to prevent back pressure
14. Umbilical cord—vacuum line
15. Pressure gage
16. Coarse adjustment valve
17. Leak free pump
18. By-pass valve
19. Dry gas meter with inlet and outlet dry gas meter thermometer
20. Orifice meter with manometer
21. Type S pitot tube with manometer
22. Stack temperature sensor

Lecture 4

DISCUSSION OF LABORATORY EXERCISES

Lesson Objectives:

The student will be able to:

- List the procedures for applying reference Method 1 at circular and rectangular stacks.
- List the steps involved in performing an "S" type pitot tube calibration.
- Describe the procedures for wet bulb dry bulb moisture estimation.
- Calibrate the meter console orifice meter when the dry gas meter has been calibrated against a reference volume standard.

I. REFERENCE METHOD I

A. Laminar Gas Flow

B. Flow Disturbance

C. Procedures

II. Lab Exercises

1. TRAVERSE POINT DETERMINATION

a. Minimum number of traverse points:

(1) Measure the inside dimensions of the duct at the sampling site. Record this data in table I.

(2) Calculate the duct equivalent diameter according to the equation.

$$D_{Eq} = \frac{2(LW)}{L+W}$$

where:

$D_{Eq'}$ = the equivalent diameter of the duct
L = the length of the duct cross-section at the sampling site
W = the width of the duct cross-section at the sampling site.

(3) Measure the distance from the sampling site to the nearest downstream flow disturbance (distance A in figure I) and from the site to the nearest upstream flow disturbance (distance B in figure I).

(4) Divide these distances by the equivalent diameter of the duct.

(5) Determine the corresponding number of traverse points for each distance from Figure I. This number must be a multiple of two.

(6) Select the higher of these two numbers. This is the minimum number of traverse points that must be used.

(7) Record all data in Table I.

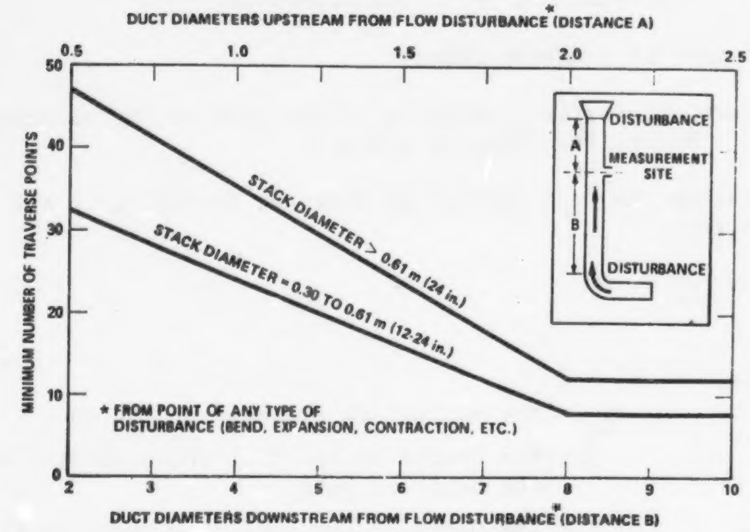


Figure I. Minimum number of traverse points.

TABLE I

NUMBER OF TRAVERSE POINTS

L= ______________________________

W= ______________________________

D_{Eq}= ______________________________

Distance A = __________________ and in equivalent diameters ________

Distance B = __________________ and in equivalent diameters ________

Number of traverse points required by distance A ______________

Number of traverse points required by distance B ______________

Required number of traverse points ______________________

b. Traverse point location.

(1) Divide the duct cross-section into as many equal rectangular areas as there are traverse points. Maintain the length-to-width ratio of these areas between 1.0 and 2.0. Use the rectangle below for diagramming.

(2) Locate a traverse point at the center of each individual area.

L/W ratio=________________

Duct cross-section lay-out

2. PITOT TUBE CALIBRATION

1. Determination of the Type S Pitot Tube Coefficient, C_p

In this exercise you will calibrate the Type S pitot tube used for velocity measurement against a standard pitot tube.

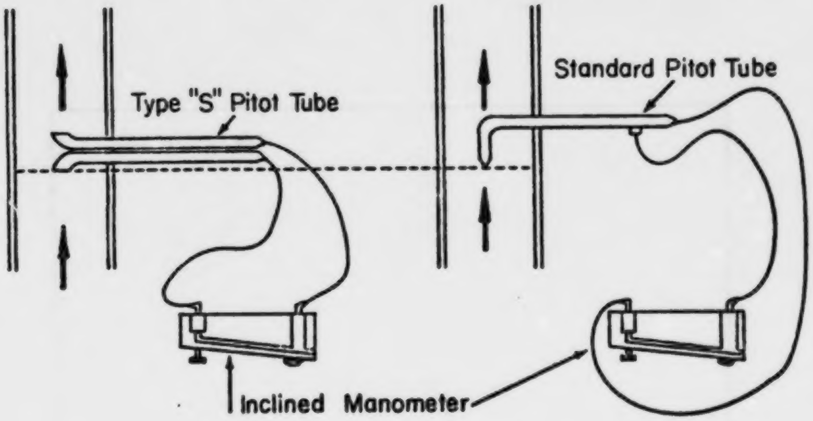


Figure 2

Procedure

a. Set-up, level and zero the inclined manometer.

b. Be sure that one tube of the type S pitot tube is labeled "A" and the other is labeled "B".

c. Place an arbitrary mark on the pitot tube such that when the mark is placed at the outside edge of the duct, the tip of the pitot tube is near the center of the duct.

d. Connect the pitot tube to the manometer as shown in Figure 2.

e. Insert the pitot tube into the duct until the mark is at the outside edge of the duct wall.

f. Align the pitot tube so that the tube labeled "A" faces directly into the flow stream.

g. Record (in Table 2) the velocity pressure indicated by the manometer.

h. Place a mark on the standard pitot tube such that when the mark is placed at the outside edge of the duct wall, the tip of the pitot tube is in exactly the same location in the duct as the Type S pitot tube was.

i. Connect the pitot tube to the manometer as shown in Figure 2.

j. Insert the tube into the duct until the mark is at the outside edge of the duct wall.

k. Align the tube so that it faces directly into the flow stream.

l. Record (in Table 2) the velocity head indicated by the manometer.

m Determine the pitot tube coefficient according to the equation

$$C_p = C_p \text{ (standard)} \sqrt{\frac{\Delta p \text{ (standard)}}{\Delta p \text{ (Type S)}}}$$

Assume the C_p (standard) is 0.99.

n. Transfer this coefficient to Table 2.

CALIBRATION OF "S" TYPE PITOT TUBE

Probe-Type "S" Pitot Tube: ID. No. ______________________

NBS Standard Pitot-Static Tube $C_p = 0.99$

Barometric Pressure ____________ Duct Gas Temperature ____________

Date ______________ Calibration Operator(s) ______________________

____

TABLE #2

S-Type Pitot Tube Coefficient Data

	Legs A, B of "S" Type Pitot Tube	Standard Pitot-Static Tube Δp in. H_2O	"S" Type Pitot Tube Δp in. H_2O	C_p Test Leg A	C_p Test Leg B
Test 1	A				▨
	B			▨	
Test 2	A				▨
	B			▨	
Test 3	A				▨
	B			▨	
			$\overline{C_p}$		

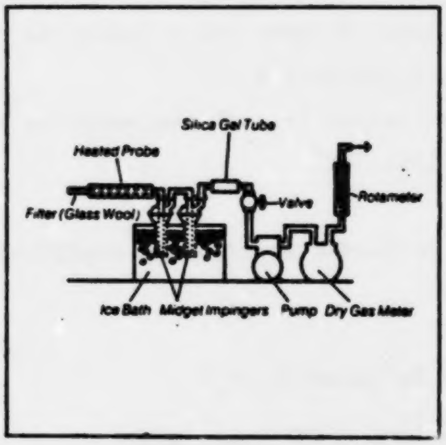
$$C_p \text{ Test} = \left[\frac{\Delta p_{\text{std}}}{\Delta p_{\text{Test}}}\right]^{1/2} C_{p_{\text{std}}}$$

3. WET BULB-DRY BULB TECHNIQUE

The determination of stack gas moisture content can be easily accomplished by either of four sampling techniques:

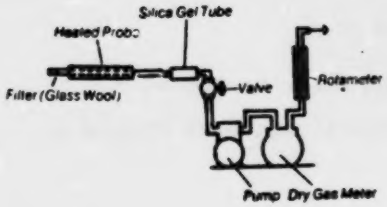
- Condensation (Federal Register Method 4)
- Adsorption (modified Federal Register Method 4)
- Wet Bulb-Dry Bulb
- Nomograph

The Federal Register Method 4 procedure for moisture determination in flue gas requires a sampling train composed of a heated probe, midget impingers and a silica gel tube. The flue gas is extracted from the source at a sampling rate of 0.75 ft^3/min or at a rate proportional to the stack gas velocity. The amount of moisture in the flue gas is determined gravimetrically and volumetrically from the impinger system/silica gel tube to give a final moisture determination.



Federal Register
Method 4
Sampling Train

Another method of determining moisture content of the flue gas relies on adsorption of the gas stream onto a desiccant (i.e. silica gel).



Modified Method 4

The amount of collected water is determined by the weight difference of the dessicant before and after sampling corrected to standard conditions employing the following two equations:

Equation (1): $B_{ws} = \frac{V_{wc}}{V_{wc} + V_{mc}}$

where B_{ws} = Proportion by volume of water vapor in the gas stream, dimensionless

V_{wc} = The volume of water vapor collected at standard conditions, ft^3

V_{mc} = Dry Gas volume through the meter at standard conditions, ft^3

The volume of water vapor collected at standard conditions, V_{wc}, is given in the following equation:

Equation (2): $V_{wc} = 0.0472\ ft^3/gram\ (V_f - V_i)$

where V_f = Final weight of M4 Tube, grams

V_i = Initial weight of M4 Tube, grams

0.0472 = The number of cubic feet that 1 gram of water would occupy in the vapor state at standard conditions.

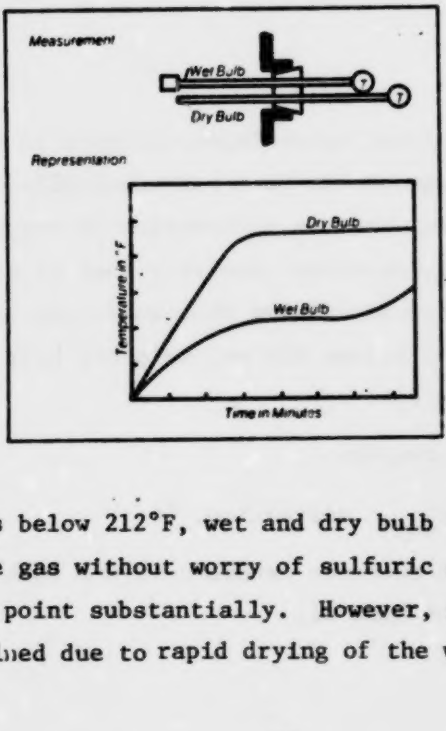
The dry gas volume of sample pulled through the meter at standard conditions can be calculated from the following equation:

$$V_{mc} = V_m Y \frac{P_m T_{std}}{P_{std} T_m}$$

where V_m = Dry gas volume measured by meter, ft^3
P_m = Barometric pressure at gas meter, in. Hg.
P_{std} = Pressure at standard conditions, 29.91 in. Hg.
T_{std} = Absolute temperature at standard conditions, 528° R
T_m = Absolute temperature at meter (F + 460), R
Y = Dry gas meter correction factor, dimensionless

Both of the above methods require some form of extracting the flue gas from the source, hence involving considerable time and effort. For approximate determination, the latter two methods serve equally well in stack gas moisture determination.

In the wet bulb/dry bulb technique, two mercury in glass thermometers are required to measure flue gas temperature. One thermometer, dry bulb, is inserted into the stack and allowed to reach equilibrium. This temperature is recorded as the dry bulb temperature. The other thermometer is covered with a cotton wick saturated with distilled water. It is also inserted into the stack and allowed to reach equilibrium. The dry bulb rapidly reaches equilibrium, while the wet bulb rises to equilibrium, levels off, and then rises again once the wick is dry. The inflection point at which the temperature reaches equilibrium is considered the wet bulb temperature.



Wet Bulb/Dry Bulb
Moisture Determination

At temperatures below 212°F, wet and dry bulb temperatures may be measured in the flue gas without worry of sulfuric acid mist being present and raising the dew point substantially. However, above 212°F, erroneous results may be obtained due to rapid drying of the wet bulb wick.

Moisture content can be calculated, using the wet bulb/dry bulb technique, from the following equation:

$$B_{ws} = \frac{V.P.}{P_{abs}} \qquad \text{Moisture Equation}$$

where: $V.P.$ = Vapor pressure of H_2O

$$= S.V.P.-(3.67\text{x}10^{-4})(P_{abs})(T_d-T_w)\left(1+\frac{t_w-32}{1571}\right)$$

$S.V.P.$ = Saturated H_2O vapor pressure at wet bulb temperature (inches of Hg) taken from table on page 31.

P_{abs} = Absolute pressure of stack gas

t_d = Temperature of dry bulb measurement, °F

t_w = Temperature of wet bulb inflection point, °F

To determine approximate moisture in a stack gas, perform the wet bulb/dry bulb technique and fill in the following equation:

$$V.P. = \underline{\quad\quad} \text{ in. Hg} - \left[3.67 \times 10^{-4}(\underline{\quad\quad} \text{ in. Hg})(\underline{\quad\quad}°F-\underline{\quad\quad}°F)\left(1+\frac{\underline{\quad\quad}°F-32°F}{1571}\right)\right]$$

$$B_{ws} = \frac{\underline{\quad\quad} \text{ in. Hg}}{\underline{\quad\quad} \text{ in. Hg}} = \underline{\quad\quad\quad\quad} \times 100 = \underline{\quad\quad\quad\quad\quad\quad} \%$$

Another method for determining approximate moisture in the flue gas is by the use of a nomograph. The nomograph has been mathematically constructed to solve various equations when known process information is supplied. While nomographs may not be as accurate as actual analysis they do provide a useful approximate moisture figure needed in solving the isokinetic ratio equation. To properly use the nomograph, determine the wet bulb/dry bulb temperatures and procede with the following steps:

(1) Calculate wet bulb depression

$$t_d - t_{wet} = \text{depression, °F}$$

(2) On the line from stack absolute pressure to wet bulb depression temperature, mark pivot line #1.

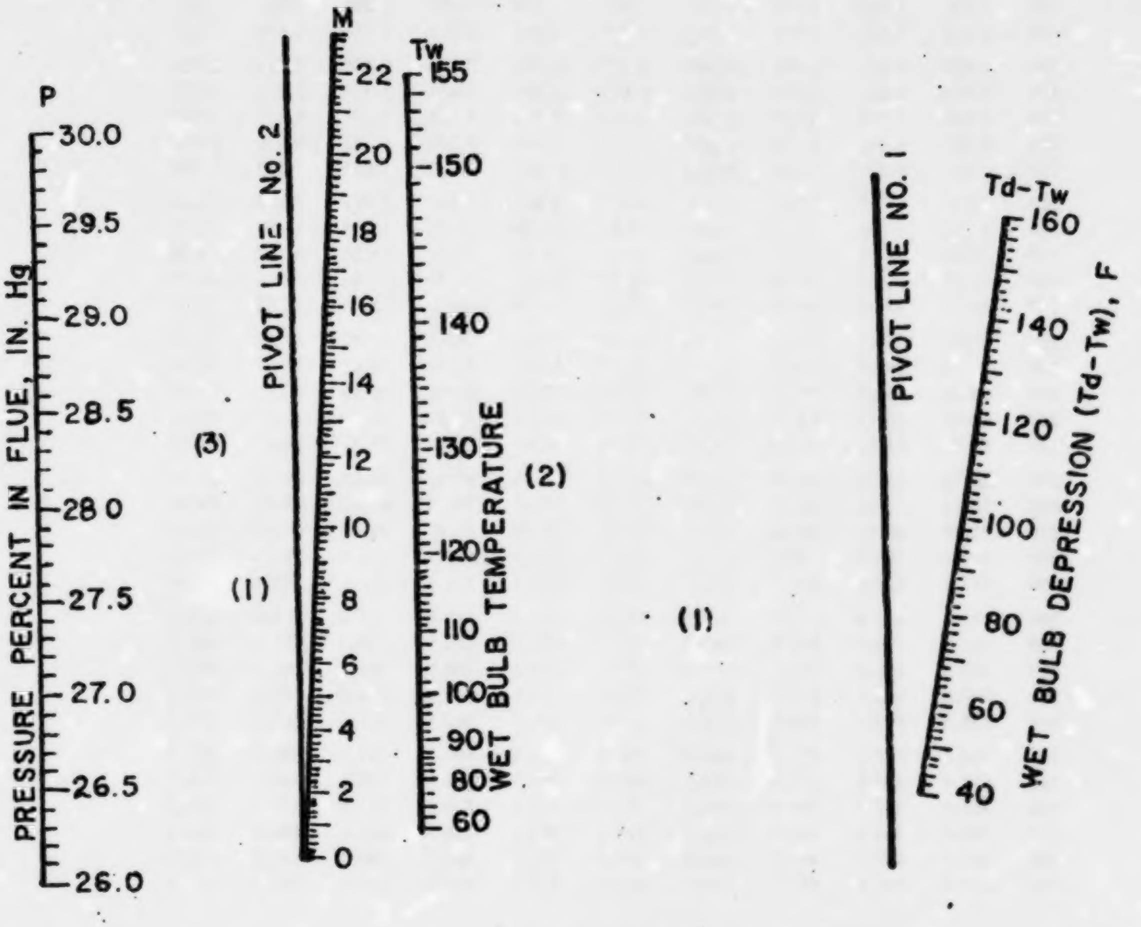
Wet Bulb Temp. Deg. F.	0	1	2	3	4	5	6	7	8	9
– – – 20	.0126	.0119	.0112	.0106	.0100	.0095	.0089	.0084	.0080	.0075
– – – 10	.0222	.0209	.0199	.0187	.0176	.0168	.0158	.0150	.0142	.0134
– – –	.0376	.0359	.0339	.0324	.0306	.0289	.0275	.0250	.0247	.0233
0	.0376	.0398	.0417	.0463	.0441	.0489	.0517	.0541	.0571	.0598
10	.0631	.0660	.0696	.0728	.0768	.0810	.0846	.0892	.0932	.0982
20	.1025	.1080	.1127	.1196	.1248	.1302	.1370	.1429	.1502	.1567
30	.1647	.1716	.1803	.1878	.1955	.2035	.2118	.2203	.2292	.2382
40	.2478	.2576	.2677	.2782	.2891	.3004	.3120	.3240	.3364	.3493
50	.3626	.3764	.3906	.4052	.4203	.4359	.4520	.4586	.4858	.5035
60	.5218	.5407	.5601	.5802	.6009	.6222	.6442	.6669	.6903	.7144
70	.7392	.7648	.7912	.8183	.8462	.8750	.9046	.9352	.9666	.9989
80	1.032	1.066	1.102	1.138	1.175	1.213	1.253	1.293	1.335	1.378
90	1.422	1.467	1.513	1.561	1.610	1.660	1.712	1.765	1.819	1.875
100	1.932	1.991	2.052	2.114	2.178	2.243	2.310	2.379	2.449	2.521
110	2.596	2.672	2.749	2.829	2.911	2.995	3.081	3.169	3.259	3.351
120	3.446	3.543	3.642	3.744	3.848	3.954	4.063	4.174	4.289	4.406
130	4.525	4.647	4.772	4.900	5.031	5.165	5.302	5.442	5.585	5.732
140	5.881	6.034	6.190	6.330	6.513	6.680	6.850	7.024	7.202	7.384
150	7.569	7.759	7.952	8.150	8.351	8.557	8.767	8.981	9.200	9.424
160	9.652	9.885	10.12	10.36	10.61	10.86	11.12	11.38	11.65	11.92
170	12.20	12.48	12.77	13.07	13.37	13.67	13.98	14.30	14.62	14.96
180	15.29	15.63	15.98	16.34	16.70	17.07	17.44	17.82	18.21	18.61
190	10.01	19.42	19.84	20.27	20.70	21.14	21.50	22.05	22.52	22.99
200	23.47	23.96	24.46	24.97	25.48	26.00	26.53	27.07	27.62	28.18
210	28.75	29.33	29.92	30.52	31.13	31.75	32.38	33.02	33.67	34.33
220	35.00	35.68	36.37	37.07	37.78	38.50	39.24	39.99	40.75	41.52
230	42.31	43.11	43.92	44.74	45.57	46.41	47.37	48.14	49.03	49.93
240	50.84	51.76	52.70	53.65	54.62	55.60	56.60	57.61	58.63	59.67
250	60.72	61.79	62.88	63.98	65.10	66.23	67.38	68.54	69.72	70.92
260	72.13	74.36	74.61	75.88	77.17	78.46	79.78	81.11	82.46	83.83
270	85.22	86.63	88.06	89.51	90.97	92.45	93.96	95.49	97.03	98.61
280	100.2	101.8	103.4	105.0	106.7	108.4	110.1	111.8	113.6	115.4
290	117.2	119.0	120.8	122.7	124.6	126.5	128.4	130.4	132.4	134.4
300	136.4	138.5	140.6	142.7	144.8	147.0	149.2	151.4	153.6	155.9
310	158.2	160.5	162.8	165.2	167.6	170.0	172.5	175.0	177.5	180.0
320	182.6	185.2	187.8	190.4	193.1	195.8	198.5	201.3	204.1	206.9
330	209.8	212.7	215.6	218.6	221.6	224.6	227.7	230.8	233.9	237.1
340	240.3	243.5	246.8	250.1	253.4	256.7	260.1	263.6	267.1	270.6
350	274.1	277.7	281.3	284.9	288.6	292.3	296.1	299.9	303.8	307.7
360	311.6	315.5	319.5	323.5	327.6	331.7	335.9	340.1	344.4	348.7
370	353.0	357.4	361.8	366.2	370.7	375.2	379.8	384.4	389.1	393.8
380	398.6	403.4	408.2	413.1	418.1	423.1	428.1	433.1	438.2	443.4
390	448.6	453.9	459.2	464.6	470.0	475.5	481.0	486.2	492.2	497.9
400	503.6	509.3	515.1	521.0	526.9	532.9	538.9	545.0	551.1	557.3

S.V.P. (Saturated H_2O vapor pressure wet bulb temperature—inches of mercury)

(3) On the line from the pivot line #1 mark and the t_w, mark on pivot line #2.

(4) On the line from the stack absolute pressure through the mark on pivot line #2 read % H_2O on scale M.

Percent Moisture in Flue Gas
Nomograph Technique



In conclusion, we have discussed four methods for determining moisture in the stack gas: condensation, adsorption, wet bulb-dry bulb and the nomograph. The method you select will depend upon your sampling parameters and degree of accuracy.

4. CALIBRATION OF THE ORIFICE METER

The orifice meter is a thin flat plate with a sharp-edged hole concentric with the axis of the diameter of the pipe in which it is located. A pressure differential is created across the orifice plate as gases flow through the concentric hole. This pressure differential is directly related to the flow rate through the orifice. A properly constructed orifice meter will locate the orifice plate at least 8 pipe diameters upstream and 2 pipe diameters downstream of any disturbances to the gas flow. The pressure differential across the plate is best measured by "Radius Taps" located 1 pipe diameter upstream and 1/2 pipe diameter downstream of the orifice plate. Improperly positioned pressure taps may not give a true representation of the gas flow rate. Calibration of the orifice meter is essential and should be performed on a regular basis.

EXERCISE

. The exercise is directed at establishing a flow rate through the orifice of 0.75cfm of dry air (M_d=29g/mole) at 68°F 29.92in. Hg. (STP). The pressure differential for this flow rate is designated $\Delta H_@$.

1. The flow rate through the orifice is calculated in the equation

$$Q_m = K_m \left[\frac{T_m \, \Delta H}{P_m \, M_m} \right]^{1/2}$$

ΔH = Pressure differential in. H_2O

K_m = Proportionality factor

Q_m = Volumetric gas flow rate (cfm)

$T_m = t_m$ (°F) + 460

P_m = Absolute pressure at the meter

M_m = Molecular weight of gas flowing through orifice

2. Solving this equation for ΔH

$$\Delta H = \left[\frac{Q_m}{K_m}\right]^2 \frac{P_m M_m}{T_m}$$

3. Substituting terms given for $\Delta H_@$

$$\Delta H_@ = \left[\frac{0.75\text{cfm}}{K_m}\right]^2 \frac{(29.92\text{in.Hg.})(29\text{g/mole})}{528^{\circ}\text{R}} = \frac{0.9244}{K_m^2}$$

. Laboratory procedures - Record data in the appropriate spaces on the form provided.

1. Turn on sampling meter console.
2. Close coarse valve and turn fine adjust valve all the way counter-clockwise.
3. Level and zero orifice manometer.
4. Partially open course valve using it and fine adjust to establish orifice ΔH.
5. Read DGM dial and simultaneously start stopwatch. Allow 2 minutes to pass maintaining proper ΔH the entire period.

6. Simultaneously close course valve and stop the watch.
7. Record final DGM reading and other data and repeat procedure for other ΔH.
8. For the higher flow rates, it may be necessary to cut off the pump while leaving the valves set, read the DGM, then simultaneously start the pump and the watch.
9. Perform calculations as illustrated on the orifice meter calibration form.

TABLE IV

Orifice Meter Calibration

Operator(s) ______________________________ Date ______________

Meter Console No. ______________ DGM No. ______________

Barometric Pressure (P_m)________in.Hg. DGM Correction Factor (DGMCF) ________

ΔH in H_2O	V_1 Initial DGM Dial Reading	Θ Minutes	V_2 Final DGM Dial Reading	Q_m (CFM)	$t_m(^\circ F)$	K_m
0.25						
0.5						
1.0						
2.0						
4.0						
6.0						
					Average ($\bar{K}_m$)	

$$\underset{(cfm)}{Q_m} = \frac{(V_2 - V_1) \text{ X DGMCF}}{\Theta(\text{minutes})}$$

$$K_m = Q_m \left[\frac{P_m \; M_m}{T_m \; \Delta H} \right]^{1/2}$$

$$\Delta H_@ = \frac{0.9244}{(\bar{K}_m)^2}$$

5. DETERMINATION OF GAS STREAM VELOCITY AND VOLUMETRIC FLOW RATE

The volumetric flow rate of a gas stream can now be determined. It is the velocity of the stream multiplied by the cross-sectional area through which it is flowing. The cross-sectional area can be determined by conventional means using diameter or circumference data for circular stacks and length and width data for rectangular stacks. Velocity, then, becomes the basic parameter necessary for volumetric flow rate calculation.

The velocity of a gas stream is determined by using a pitot tube. The pitot tube equation can be written as

$$V_s = K_p C_p (\sqrt{\Delta p})_{ave} \sqrt{\frac{T_s}{P_s M_s}}$$

where:

V_s = velocity of the gas stream, ft /sec

T_s = absolute temperature, °R (°F + 460)

P_s = absolute pressure, in. Hg

M_s = molecular weight of the gas, lb /lb -mole

Δp = velocity pressure, in. H_2O

K_p = constant: $85.49 \sqrt{\frac{ft^2 \text{ in. Hg lbs /lb -mole}}{sec^2 \text{ in. } H_2O \text{ °R}}}$ for the above dimensions

C_p = pitot tube coefficient, dimensionless.

The volumetric flow rate of a gas stream is calculated according to the equations: Actual Stack Gas Volumetric Flow Rate

$$Q_a = v_s A$$

Stack Gas Volumetric Flow Rate corrected to standard conditions

$$Q_s = 3600 \text{ sec/hr } (1-B_{ws})\, v_s A \left(\frac{T_{std}}{T_s}\right)\left(\frac{P_s}{P_{std}}\right)$$

where:

Q_a = the volumetric flow rate of the gas stream at actual conditions in cubic feet per hour (acfh)

Q_s = the volumetric flow rate of the gas stream on a dry basis at standard conditions in cubic feet per hour (scfh)

3600 = conversion factor (3600 sec /hr)

B_{ws} = the moisture fraction by volume of the gas stream (dimensionless)

v_s = the velocity of the gas stream at the sampling site (ft /sec)

A = the cross-sectional area of the gas stream at the sampling site (ft ^{2})

T_{std} = the absolute temperature at standard conditions (528° R)

T_s = the average, absolute temperature of the gas stream (°R)

P_s = the average, absolute pressure of the gas stream (in. Hg)

P_{std} = the absolute pressure at standard conditions (29.92 in. Hg).

In order to calculate the velocity, v_s, and the volumetric flow rate, Q_s, you must measure C_p, T_s , Δp, P_s, M_s, and A. You will notice that in order to determine the molecular weight, M_s, there are two steps--the determination of the molecular weight (M_d) of the gas stream on a dry basis and the determination of the moisture content (B_{ws}) of the gas stream.

Procedures:

Determine the following:

1. Pitot tube coefficient (C_p).
2. Velocity pressure (Δp).
3. Molecular weight (M_d).
4. Stack pressure (P_s).
5. Stack temperature (T_s).
6. Moisture fraction (B_{ws}).

When you have conducted the exercises and made the appropriate calculations, transfer the data to Table III and calculate the velocity.

For this exercise, assume a M_d of 29.0 and a B_{ws} as determined in wet bulb-dry bulb lab.

TABLE III

VELOCITY AND VOLUMETRIC FLOW RATE CALCULATIONS

A = ______________________________

K_p = 85.49______________________________

C_p = ______________________________

$(\sqrt{\Delta p} =)_{ave}$ ______________________________ $(\text{in. } H_2O)^{1/2}$

T_s = ______________________________ °R

P_s = ______________________________ in. Hg

M_d = ______________________________ lb/lb-mole

B_{ws} = ______________________________ moisture fraction

$M_s = M_d\ (1-B_{ws}) + 18\ B_{ws}$ = ______________________

$$v_s = K_p\ C_p (\sqrt{\Delta p})_{ave} \sqrt{\frac{T_s}{P_s\ M_s}} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

$$Q_s = 3600 \text{ sec /hr } (1 - B_{ws})\ v_s\ A \left(\frac{T_{std}}{T_s}\right)\left(\frac{P_s}{P_{std}}\right) = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

Name ______________________

Group no. ______________________

Date ______________________

DATA SUMMARY

1. Stack diameter ______________________
2. Equivalent diameter (D_E) ______________________
3. Number of sampling points required ______________________
4. Standard pitot tube C_p ______________________
5. Type S pitot tube C_p ______________________
6. Barometric pressure (P_b) ______________________
7. Absolute stack pressure (P_s) ______________________
8. Meter temperature (T_m) ______________________
9. Stack temperature (T_s) ______________________
10. % Moisture in stack gas ______________________
11. Dry molecular weight of stack gas (M_d) ______________________
12. Wet molecular weight of stack gas (M_s) ______________________
13. Average gas velocity (v_s) ______________________
14. Average stack volumetric flow rate
    Actual (Q_a) ______________________
    Standard (Q_s) ______________________
15. Meter console no. ______________ $\Delta H_@$ ______________

Name ____________________

Group no. ____________________

Date ____________________

DATA SUMMARY

1. Stack diameter ____________________
2. Equivalent diameter (D_E) ____________________
3. Number of sampling points required ____________________
4. Standard pitot tube C_p ____________________
5. Type S pitot tube C_p ____________________
6. Barometric pressure (P_b) ____________________
7. Absolute stack pressure (P_s) ____________________
8. Meter temperature (T_m) ____________________
9. Stack temperature (T_s) ____________________
10. % Moisture in stack gas ____________________
11. Dry molecular weight of stack gas (M_d) ____________________
12. Wet molecular weight of stack gas (M_s) ____________________
13. Average gas velocity (v_s) ____________________
14. Average stack volumetric flow rate
    Actual (Q_a) ____________________
    Standard (Q_s) ____________________
15. Meter console no. ____________________ $\Delta H_@$ ____________________

This sheet is to be handed in Wednesday morning.

Lectures 5 & 6

ISOKINETIC SOURCE SAMPLING AND ISOKINETIC RATE EQUATIONS

Lesson Objectives:

The student will be able to:

- Define isokinetic sampling.
- Illustrate why isokinetic sampling is necessary when sampling for particulate emissions.
- State how the particulate concentration given by the Method 5 train will change when the sampling is performed overisokinetically .
- State how the particulate concentration given by the Method 5 train will change when the sampling is performed underisokinetically .
- Recall the basic equation for establishing the isokinetic rate, $\Delta H = K \Delta p$
- Explain that gas passing through the sampling train undergoes changes of moisture content, temperature, and pressure.
- Explain that the isokinetic rate equation is derived from the requirement that v_n must equal v_s, and that one obtains the final expression by substituting the pitot tube equation and orifice meter equation and by making proper corrections for pressure, temperature, and moisture content.
- Recognize the fact that a separate equation exists for the determination of the nozzle diameter.
- Calculate the value of D_n, the nozzle diameter, given the appropriate input data, using a calculator or a slide rule.

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- **Calculate the value of K and ΔH, given the appropriate input data, using a calculator or a slide rule.**

- **Calculate values of D_n, K, and ΔH using a source sampling nomograph.**

- **State the assumptions of the source sampling nomograph.**

- **Check the accuracy of the source sampling nomograph and recognize the effect of errors in computed ΔH values on test results.**

ISOKINETIC SAMPLING

Isokinetic sampling conditions exist when the velocity of the gases entering the probe nozzle tip (v_n) is exactly equal to the velocity of the approaching stack gases (v_s), that is $v_n = v_s$. The percent isokinetic is defined as:

$$\% \text{ isokinetic} = \frac{v_n}{v_s} \times 100$$

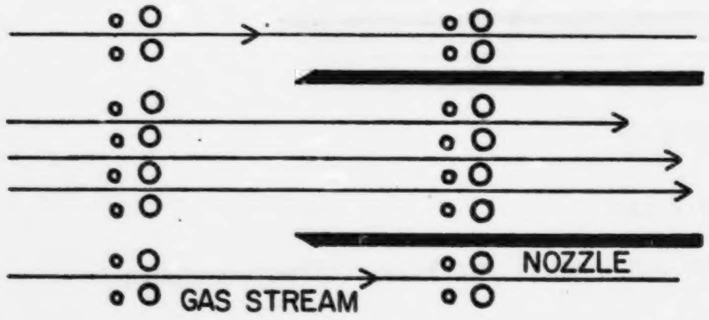
and is equal to 100% only when $v_n = v_s$. When $v_n \neq v_s$ (anisokinetic conditions), sample concentrations can be biased due to the inertial effects of particles.

If the gas-flow streamlines are disturbed as in anisokinetic conditions:

1. Large particles tend to move in the same initial direction.
2. Small particles tend to follow the streamlines.
3. Intermediate particles are somewhat deflected.

As an example, assume that we have a large particle of 6 mass units and a small particle of .03 mass units. Consider the following situations:

100% ISOKINETIC



Assume

$v_n = v_s$

$Q_n = 1$ cfm

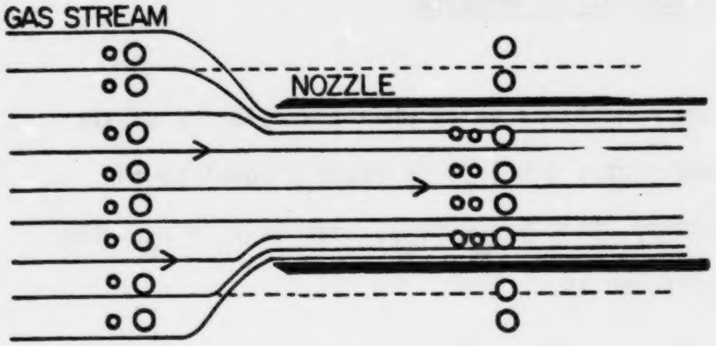
4 large and 4 small particles are collected/minute

Therefore:

$$\text{mass/minute} = 4\text{x}6 + 4\text{x}.03 = 24.1 \ \frac{\text{mass units}}{\text{minute}}$$

$$C_n = \frac{24.1}{1} \ \frac{\text{m.u./min}}{\text{ft}^3\text{/min}} = 24.1 \ \frac{\text{m.u.}}{\text{ft}^3}$$

200% ISOKINETIC



Assume: $v_n = 2v_s$

$Q_n = 2\text{cfm}$

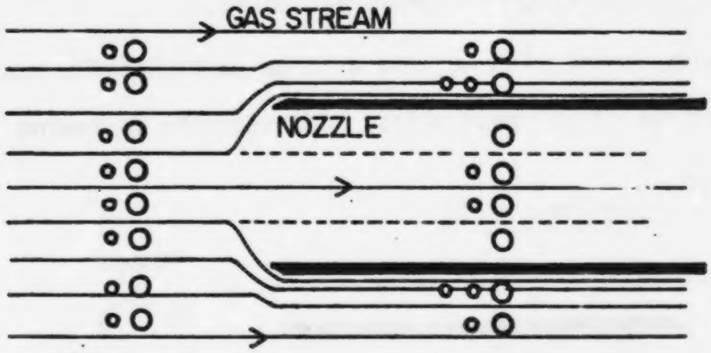
4 large and 8 small particles collected/minute

Therefore:

mass/minute = 4 x 6 + 8 x .03 = 24.2 m.u./minute

$$C_n = \frac{24.2}{2} \quad \frac{\text{m.u./min}}{\text{ft}^3\text{/min}} = 12.1 \quad \frac{\text{m.u.}}{\text{ft}^3}$$

50% ISOKINETIC



Assume: $v_n = 1/2\ v_s$

$Q_n = 1/2\ \text{cfm}$

4 large and 2 small particles collected/minute

Therefore:

mass/minute = 4 x 6 + 2 x .03 = 24.1 m.u./minute

$$C_n = \frac{24.1}{1/2} \quad \frac{\text{m.u./min}}{\text{ft}^3\text{/min}} = 48.2\ \frac{\text{m.u.}}{\text{ft}^3}$$

The criteria of what particle sizes constitute large, intermediate, and small particles is a function of the particle density stack velocity, gas viscosity, and nozzle diameter. Various studies have been made to determine this relationship. The following are some references.

1. S. Badzioch, "Correction for Anisokinetic Sampling of Gas-borne Dust Particles" J. Inst. Fuel, 106-110 (March 1960).
2. W.C.L. Hemeon and G.F. Haines, Jr., "The Magnitude of Errors in Stack Dust Sampling" Air Repair 4, 159-164 (November 1954).
3. H.H. Watson, "Errors Due to Anisokinetic Sampling of Aerosols" Ind. Hyg. Quart., 21-25 (March 1954).
4. S. Badzioch, "Collection of Gas-borne Dust Particles by Means of an Aspirated Sampling Nozzle", Brit. J. Appl.Phys. 10, 26-32 (January 1959).
5. V. Vitols, "Theoretical Limits of Errors Due to Anisokinetic Sampling of Particulate Matter" J. APCA 16, 79-84 (February 1966).

$$\Delta H = K \Delta p$$

SIMPLIFIED
ISOKINETIC
RATE EQUATION

$$Q_n = A_n v_n = A_n v_s = \frac{\pi D_n^2}{4} v_s$$

NOZZLE TIP VOLUMETRIC FLOW RATE

$$Q_m = K_m \sqrt{\frac{T_m \Delta H}{P_m M_m}}$$

ORIFICE METER EQUATION

T and P CORRECTION
FOR DRY GAS STREAM

$$Q_n = \frac{P_m}{P_s} \frac{T_s}{T_m} Q_m$$

$$n_s (1 - B_{ws}) = n_m (1 - B_{wm})$$

MOISTURE CORRECTION

$$Q_n = \frac{1 - B_{wm}}{1 - B_{ws}} \frac{T_s}{T_m} \frac{P_m}{P_s} Q_m$$

FLOW RATE CORRECTED FOR T, P & MOISTURE

$$Q_n = \frac{(1 - B_{wm})\, T_s\, P_m}{(1 - B_{ws})\, T_m\, P_s}\, K_m \sqrt{\frac{T_m \Delta H}{P_m\, M_m}}$$

RELATION OF FLOW RATE AT NOZZLE TO METER FLOW RATE

$$\frac{\pi D_n^2}{4}\, v_s = \frac{(1 - B_{wm})}{(1 - B_{ws})}\, \frac{T_s}{T_m}\, \frac{P_m}{P_s}\, K_m \sqrt{\frac{T_m\, \Delta H}{P_m\, M_m}}$$

$$v_s = K_p c_p \sqrt{\frac{T_s \Delta p}{P_s M_s}}$$

PITOT TUBE EQUATION

$$\frac{\pi D_n^2}{4} K_p C_p \sqrt{\frac{T_s \Delta p}{P_s M_s}} =$$

$$\frac{(1 - B_{wm})}{(1 - B_{ws})} \frac{T_s}{T_m} \frac{P_m}{P_s} K_m \sqrt{\frac{T_m \Delta H}{P_m M_m}}$$

$$\Delta H = \left\{ D_n^4 \left(\frac{\pi K_p C_p}{4 K_m} \right)^2 \frac{(1 - Bws)^2}{(1 - B_{wm})^2} \frac{M_m}{M_s} \frac{T_m P_s}{T_s P_m} \right\} \Delta p$$

SOLVING FOR ΔH

$M_m = M_d(1 - B_{wm}) + 18\,B_{wm}$

$M_s = M_d(1 - B_{ws}) + 18\,B_{ws}$

MOISTURE RELATIONSHIPS

$$\Delta H = \left\{ D_n{}^4 \left(\frac{\pi K_p C_p}{4K_m} \right)^2 \frac{(1 - B_{ws})^2}{(1 - B_{wm})^2} \frac{\left[M_d(1 - B_{wm}) + 18\,B_{wm} \right]}{\left[M_d(1 - B_{ws}) + 18\,B_{ws} \right]} \frac{T_m P_s}{T_s P_m} \right\} \Delta p$$

ISOKINETIC RATE EQUATION

$\Delta H_@$ IS DEFINED AS THE ORIFICE PRESSURE DIFFERENTIAL THAT GIVES 0.75 CFM OF AIR AT 68^o F AND 29.92" Hg.

$$\Delta H = \frac{Q_m^2}{K_m^2} \frac{P_m M_m}{T_m}$$

$$\Delta H_@ = \frac{(.75\text{cfm})^2 \; (29.92''\ \text{Hg})\ (29.0)}{(460 + 68)\ K_m^2}$$

$$\Delta H_@ = \frac{.9244}{K_m^2}$$

SIMPLIFYING

ASSUME $B_{wm} = 0$

LET $\Delta H_{@} = \dfrac{.9244}{(K_m)^2}$

AND $K_p = 85.49$

ISOKINETIC RATE EQUATION – WORKING FORM

$$\Delta H = \left\{ 846.72\ D_n^4\ \Delta H_{@}\ C_p^2\ (1 - B_{ws})^2\ \frac{M_d}{M_s}\ \frac{T_m}{T_s}\ \frac{P_s}{P_m} \right\} \Delta p$$

$$D_n = \sqrt{\left(\frac{.0358\ Q_m P_m}{T_m\ C_p (1 - B_{ws})}\right) \sqrt{\frac{T_s M_s}{P_s\ (\Delta p)}}}$$

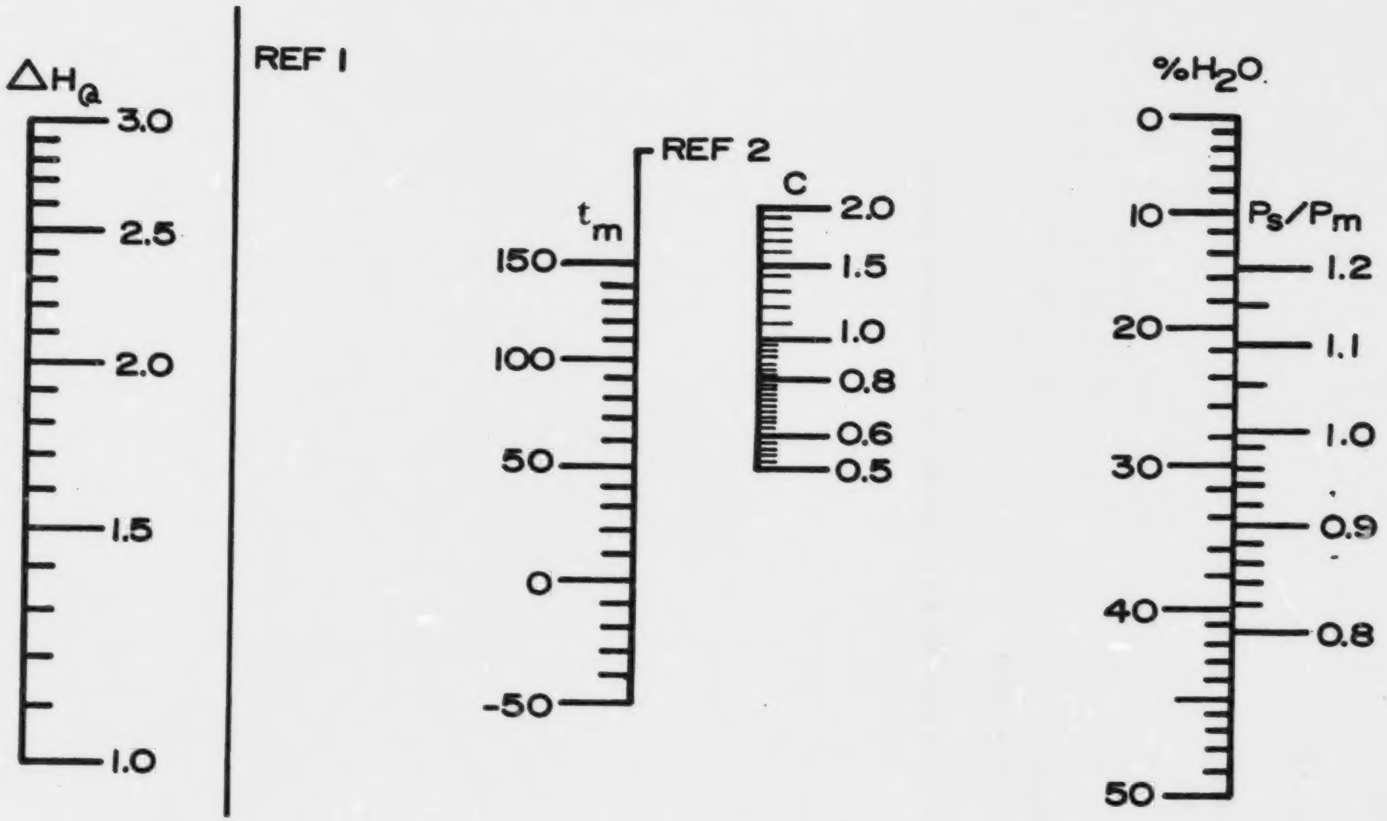
NOZZLE DIAMETER SELECTION

ISOKINETIC ΔH LECTURE PROBLEM

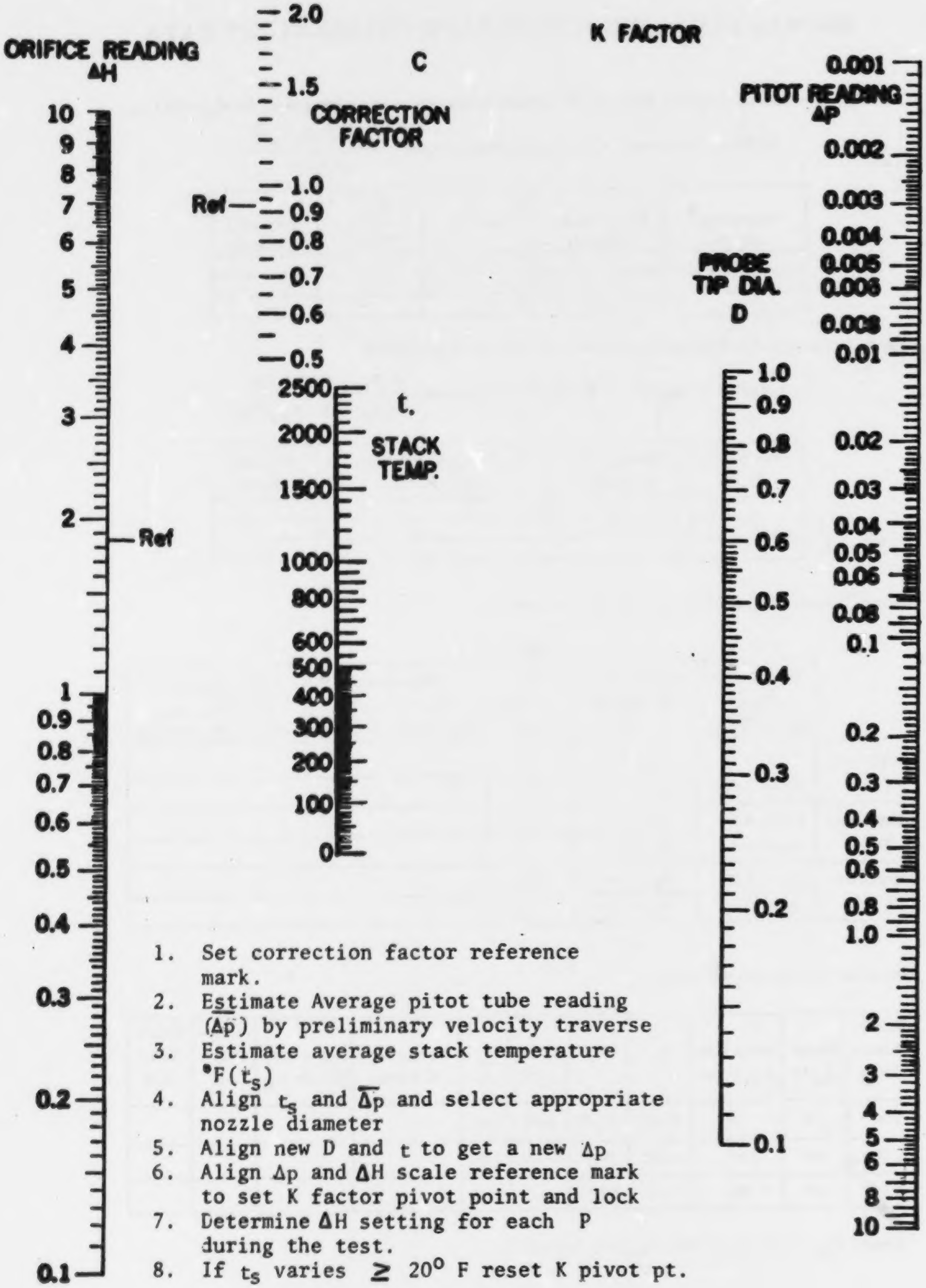
Given the following information use the isokinetic ΔH equation to find a K factor for setting isokinetic rate through the sampling train:

$Q_m = 0.75\ CFM$
$\Delta H_@ = 1.85$
$Pitot\ tube\ C_p = 0.85$
$t_m = 80°F$
$P_m = 30.0\ in.\ Hg$
$P_s = 29.6\ in.\ Hg$
$B_{wm} = 0$
$B_{ws} = 0.12$
$t_s = 280°F$
$M_d = 29\ lb/lb\text{-}mole$
$Average\ \Delta p = 0.80\ in.\ H_2O$

You will need to find M_s then solve the equations for nozzle diameter and K.



DRAW LINE FROM $\Delta H_@$ TO t_m TO OBTAIN POINT A ON REF. 1.
DRAW LINE FROM POINT A TO $\% H_2O$ AND READ B ON REF. 2.
DRAW LINE FROM POINT B TO P_s/P_m.



1. Set correction factor reference mark.
2. Estimate Average pitot tube reading ($\overline{\Delta p}$) by preliminary velocity traverse
3. Estimate average stack temperature °F(t_s)
4. Align t_s and $\overline{\Delta p}$ and select appropriate nozzle diameter
5. Align new D and t to get a new Δp
6. Align Δp and ΔH scale reference mark to set K factor pivot point and lock
7. Determine ΔH setting for each P during the test.
8. If t_s varies ≥ 20° F reset K pivot pt.

SOURCE SAMPLING NOMOGRAPH CALIBRATION DATA

Form A. Correct the C-Factor obtained in normal operation of the nomograph for $C_p \neq 0.85$ by:

$$\text{C-Factor (Adjusted)} = (\text{C-Factor Nomograph})\ \frac{(\text{Pitot Tube } C_p)^2}{(0.85)^2}$$

Nomograph ID. No.	Nomograph C-Factor	Pitot C_p	$\frac{(C_p)^2}{(0.85)^2}$	Adjusted C-Factor

Form B. Correct the Nomograph C-Factor for $M_d \neq 29$ lb/lb-mole

$$\text{C-Factor (Adjusted)} = (\text{C-Factor Nomograph})\ \frac{1\text{-}B_{ws} + 18\ B_{ws}/29}{1\text{-}B_{ws} + 18\ \ B_{ws}/M_d}$$

Nomograph ID. No.	Nomograph C-Factor	Stack Gas Dry Molecular Weight (M_d)	Adjusted C-Factor

Form C. Scale Alignment (Check all Nomographs)

	Step 1	Step 2	Step 3		
	Set marker on and tighten pivot	Set one end of marker on	ΔH should read	Nomograph ID. No.____ actual ΔH reading	Nomograph ID. No.____ actual ΔH reading
Alignment Test 1	ΔH = 0.1	Δp = 0.01	1.0		
	Δp = 0.001	Δp = 0.1	10.0		
Alignment Test 2	ΔH = 10.0	Δp = 1.0	1.0		
	Δp = 10.0	Δp = 0.1	.1		
Alignment Test 3	ΔH = 1.0	Δp = 1.0	10.0		
	Δp = 0.1	Δp = 0.01	.1		

Form D. Nomograph Accuracy*

Meter Console $\Delta H_@$	Meter t_m °F	Stack Gas $B_{ws} \times 100$	P_s	P_m	Stack t_s °F	$\overline{\Delta p}$	Nomograph C-Factor	Calculated Nozzle D_n	Nomograph ΔH	Calculated ΔH
1.84*	70	5	29.92	29.92	1000	1.00				
1.00	140	10	29.92	29.92	300	2.00				
2.00*	100	30	35.9	29.92	500	2.00				

***Assume $Q_m = 0.75$; $C_p = 0.85$; $B_{wm} = 0$; $M_d = 29.0$**

Forms for source sampling nomograph calibration.

Name ______________________________
Nomograph No. ______________________

Homework Problem
Setting the Isokinetic Sampling Rate

This problem gives practice in obtaining the isokinetic sampling rate using two methods – the nomograph method and the calculation method. Using the data given in Table 1, fill in the boxes of Table 2 for problems 1, 2, and 3.

Note the following:

1. Assume $B_{wm} = 0$ for all problems. Assume $Q_m = .75$.
2. In problem 3, correct the nomograph C factor for different Cp and for different M_d.
3. Remember that $M_s = M_d(1 - B_{ws}) + 18\ B_{ws}$.
4. Equations for D_n and ΔH are page 52 of the workbook.

Table 1

Problem Number	$\Delta H_@$	C_p	t_m	t_s	P_s	P_m	B_{ws}	M_d	$\widetilde{\Delta p}$
1.	1.84	.85	70	1000	29.92	29.92	.05	29.0	1.0
2.	1.00	.85	140	300	29.92	29.92	.10	29.0	2.0
3.	2.00	.80	100	500	29.70	31.9	.30	26.2	.75

Table 2

Problem Number	M_s	D_n (calc.)	K (calc.)	C (nomo.)	D_n (nomo.)	ΔH if $\Delta p = 1.0$ (nomo.)	ΔH if $\Delta p = 1.0$ (calc.)	ΔH if $\Delta p = 1.3$ (nomo.)	ΔH if $\Delta p = 1.3$ (calc.)	ΔH if $\Delta p = .8$ (nomo.)	ΔH if $\Delta p = .8$ (calc.)
1.											
2.											
3.											

Name ______________________________

Nomograph No. ____________________

HAND IN SHEET
Homework Problem
Setting the Isokinetic Sampling Rate

This problem gives practice in obtaining the isokinetic sampling rate using two methods—the nomograph method and the calculation method. Using the data given in Table 1, fill in the boxes of Table 2 for problems 1, 2, and 3.

Note the following:

1. Assume $B_{wm} = 0$ for all problems. Assume $Q_m = .75$.
2. In problem 3, correct the nomograph C factor for different Cp and for different M_d.
3. Remember that $M_s = M_d(1 - B_{ws}) + 18\ B_{ws}$.
4. Equations for D_n and ΔH are page 52 of the workbook.

Table 1

Problem Number	$\Delta H_@$	C_p	t_m	t_s	P_s	P_m	B_{ws}	M_d	$\tilde{\Delta p}$
1.	1.84	.85	70	1000	29.92	29.92	.05	29.0	1.0
2.	1.00	.85	140	300	29.92	29.92	.10	29.0	2.0
3.	2.00	.80	100	500	29.70	31.9	.30	26.2	.75

Table 2

Problem Number	M_s	D_n (calc.)	K (calc.)	C (nomo.)	D_n (nomo.)	ΔH if $\Delta p = 1.0$ (nomo.)	ΔH if $\Delta p = 1.0$ (calc.)	ΔH if $\Delta p = 1.3$ (nomo.)	ΔH if $\Delta p = 1.3$ (calc.)	ΔH if $\Delta p = .8$ (nomo.)	ΔH if $\Delta p = .8$ (calc.)
1.											
2.											
3.											

(To be handed in Wednesday morning)

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Lecture 7

REVIEW OF REFERENCE METHODS 1-4

Lesson Objectives:

The student will be able to:

- Fully describe and perform RM1 procedures.
- List all Federal Register requirements for pitot tube calibration, construction, and use.
- Describe RM4 procedures for moisture determination.
- Use RM4 equations for calculation of B_{ws} .
- List the procedures for RM3 gas analysis.
- Calculate and mathematically define.
  a. M_d
  b. M_s
  c. %Excess air

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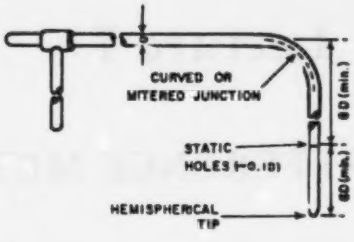
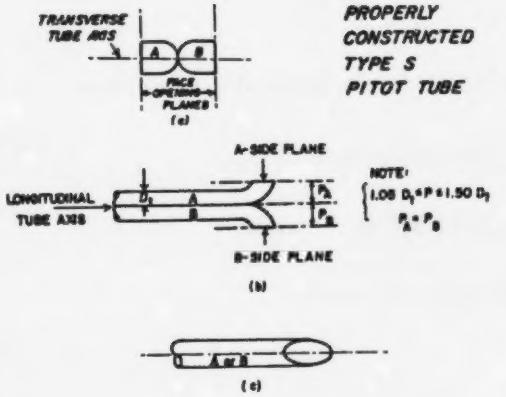
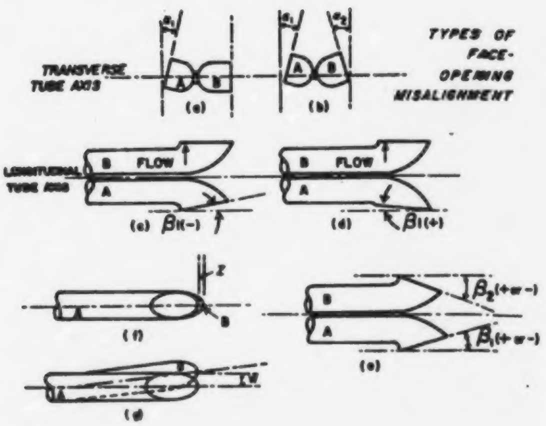
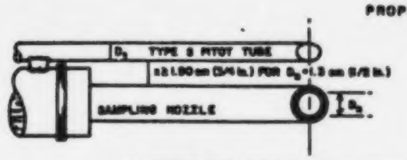


Standard Pitot Tube
Design Specifications

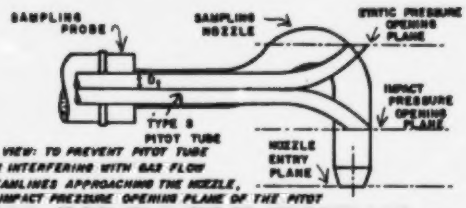




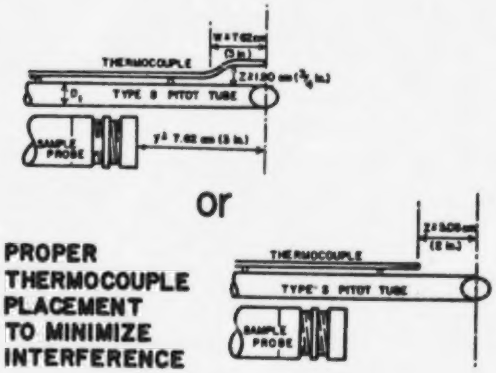
PROPER PITOT TUBE-SAMPLING NOZZLE CONFIGURATION TO MINIMIZE AERODYNAMIC INTERFERENCE



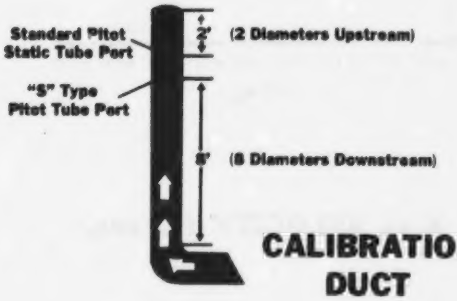
A. BOTTOM VIEW: SHOWING MINIMUM PITOT-NOZZLE SEPARATION



B. SIDE VIEW: TO PREVENT PITOT TUBE FROM INTERFERING WITH GAS FLOW STREAMLINES APPROACHING THE NOZZLE, THE IMPACT PRESSURE OPENING PLANE OF THE PITOT TUBE SHALL BE EVEN WITH OR ABOVE THE NOZZLE ENTRY PLANE.



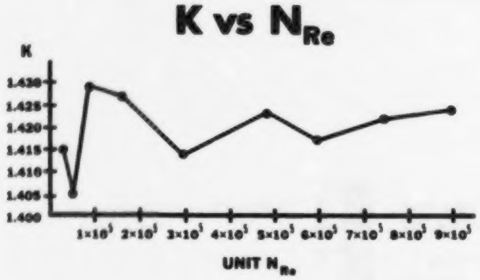
PROPER THERMOCOUPLE PLACEMENT TO MINIMIZE INTERFERENCE

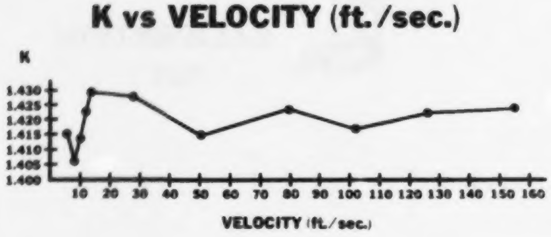


Standard Pitot Static Tube Port
"S" Type Pitot Tube Port
2' (2 Diameters Upstream)
8' (8 Diameters Downstream)

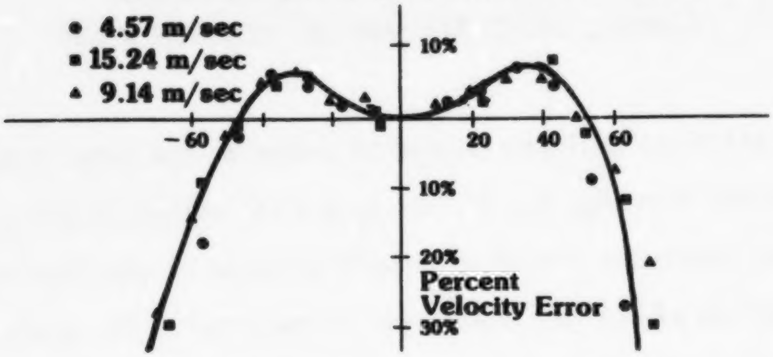
CALIBRATION DUCT

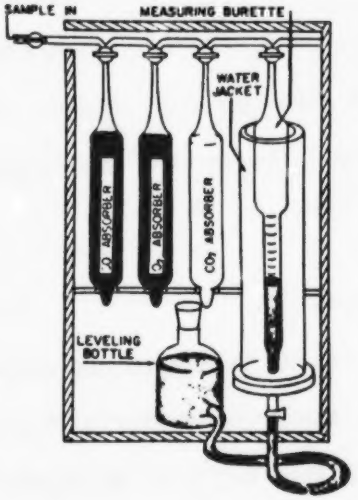
NOTES:


K vs N_{Re}


K vs VELOCITY (ft./sec.)

**VELOCITY ERROR VS
YAW ANGLE FOR AN S-TYPE PITOT TUBE**





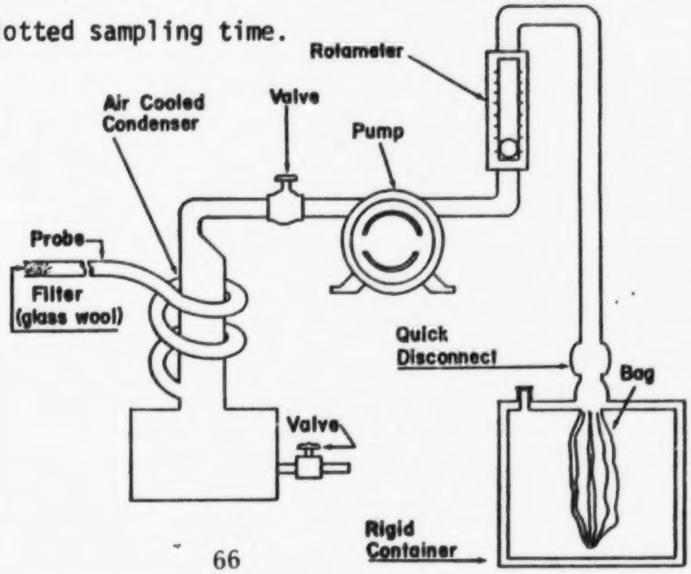
LABORATORY EXERCISE

GAS ANALYSIS DETERMINATION FOR CARBON DIOXIDE, EXCESS AIR, AND DRY MOLECULAR WEIGHT

The orsat gas analyzer is used to determine the composition of the stack gas when CO_2, O_2, CO, and N_2 are the principle gas constituents. An integrated Tedlar bag sample is taken of the stack gas and a known volume of the gas is analyzed in the orsat. The composition of the gas is determined on a percent by volume basis. This is accomplished by successive removal of CO_2, O_2, and CO with N_2 calculated by difference. The data are defined by Dalton's Law of Partial Pressure and the Ideal Gas Law as the mole fraction of each constituent gas. The vapor pressure of H_2O in the orsat analyzer is constant, therefore, all data are given on a dry basis. An outline of the procedure is presented here. Please read the Federal Register for complete understanding.

I. Integrated Bag Sample

A. The sampling set up is diagrammed below. A sample rate proportional to the stack gas velocity is arbitrarily set, such that the evacuated bag will be approximately 2/3 full after the allotted sampling time.



B. This apparatus will be assembled for the student and be in operation.

   1. Inspect all aspects of this apparatus for complete understanding.
   2. Proceed to Orsat when bag is filled.

II. Orsat Analysis

A. Level the analysis solutions to the mark on the analysis bottle using the burette leveling bottle.

   1. Turn burette stopcock to vent and raise leveling bottle.
      a. red burette solution (saturated Na_2SO_4 with H_2SO_4 to make it acidic and methyl orange indicator) will fill burette.
      b. close the stopcock.
      c. Crimp leveling bottle tubing with the palm of your hand.
   2. Open burette stopcock and the stopcock of the CO_2 bubbler bottle so that gas can enter each container.
      a. Slowly release leveling bottle tubing crimp while lowering the bottle.
      b. The CO_2 absorbing solution (42% KOH) will rise in the bubbler.
      c. Raise CO_2 solution to the reference mark on the small diameter pipette very slowly (use the palm of your hand to make a tubing crimp as a regulator). Do not mix solutions.
      d. Close stopcock to CO_2 bubbler leave burette stopcock open to pipette gas to other bubblers.

3. Repeat procedure for other bubblers.
   a. O_2 (46% KOH and pyrogallic acid)
   b. CO (CuCl in solution with hydrogen and copper ions to prevent oxidation to CU^{++} Cl^-.)

B. Leak test the burette and analysis bottles
   1. Close stopcocks after bringing analysis solutions in each bottle to reference mark.
   2. Level burette solution at mid-scale. Close stopcock and record reading.
   3. Allow analyzer to stand 4 minutes then note level of each solution.
   4. For any solution that has fallen from the mark, regrease the stopcock and check for location(s) of leak. Repeat leak test until analyzer holds marks for 4 minutes.

C. Analyze gas sample
   1. Record all information on the Orsat Field Data Sheet
   2. Fill the burette with 100cc of gas from the integrated bag sample.
   3. Determine the percent by volume in the following sequence : CO_2, O_2, CO.
      a. Open the CO_2 stopcock to the burette.
      b. Let the gas mix by bubbling through the CO_2 bottle three times using the leveling bottle to move the gas back and forth through the liquid.
      c. Bring CO_2 solution back to the reference mark and close the stopcock. Do not mix solutions.

d. Read burette by leveling solution in burette and solution in leveling bottle (both at atmospheric pressure)

e. Repeat 1 pass only to assure all CO_2 has been scrubbed out and record the constant readings.

f. Repeat all procedures for O_2 (≈10 passes) and CO (≈3 passes)

Dry molecular weight determination

Plant
Date
Sampling time (24 hr clock)
Sampling location
Sample type (bag, integrated, continuous)
Analytical method
Ambient temperature
Operator

Comments:

Run / Gas	1 Reading		2 Reading		3 Reading		Average net Volume	Multiplier	Molecular weight of stack gas (dry basis) M_d (lb/lb-mole)
	Actual	Net	Actual	Net	Actual	Net			
CO_2								.44	
O_2 (net is actual O_2 reading minus actual CO_2 reading)								.32	
CO (net is actual CO reading minus actual O_2 reading								.28	
N_2 (net is 100 minus actual CO reading								.28	
								Total	

$$M_d = .44(\%CO_2) + .32(\%O_2) + .28(\%CO + \%N_2)$$

Lecture 8

CALCULATION AND INTERPRETATION OF % ISOKINETIC

Lesson Objectives:

The student will be able to:

- Locate the equations for %I in the Federal Register and in the course workbook.
- Explain how the %I expression is derived.
- Explain the relative importance of the variables in the %I expression and point out which ones should be closely checked on the source test report.
- Illustrate the effect of underisokinetic sampling on the measured pmr, relative to the true pmr.
- Illustrate the effect of overisokinetic sampling on the measured pmr, relative to the true pmr.
- Evaluate whether a source test should be rejected or accepted, based upon the value of the % isokinetic and whether the emission rate value is above or below the standard.

DERIVATION
# of the
ISOKINETIC
VARIATION
EQUATION

$$\text{\% Isokinetic Variation} = \frac{V_n}{V_s} \times 100$$

V_n = velocity of gas through nozzle

V_s = stack gas velocity

From the equation
of continuity

$$v_n = \frac{Q_n}{A_n}$$

Q_n FROM COLLECTED DATA

$$Q_n = \frac{V_{sw} + V_{\text{meter corrected}}}{\theta}$$

where θ = SAMPLING TIME PERIOD

$$V_{\substack{\text{Orifice}\\ \text{Corrected}}} = \left(\frac{T_s}{P_s} \, \frac{\left(P_b + \frac{\Delta H}{13.6}\right)}{T_m} \right) V_m$$

Correction of Metered Volume to Volume at Stack Conditions
Correction for Water Collected in Impingers

$$V_{1c}\ \rho H_2O = m_{H_2O}$$

$$P_sV_{sw} = \frac{m}{M} RT_s$$

and $$V_{sw} = m_{H_2O} \frac{RT_s}{M_{H_2O} P_s}$$

$$V_{sw} = V_{1c}\ \rho H_2O \frac{RT_s}{M_{H_2O}P_s}$$ = The volume of water vapor at stack conditions

SUBSTITUTING INTO Q_n

$$Q_n = \frac{\frac{T_s}{P_s}\left[V_{1c} K_3 + \frac{V_m}{T_m} (P_b + \frac{\Delta H}{13.6})\right]}{\theta}$$

WHERE $K_3 = \frac{\rho H_2O\ R}{M_{H_2O}} = .00267 \frac{\text{in Hg ft}^3}{\text{ml }^oR}$

DERIVATION OF % I

$$\% \; I = \frac{v_n}{v_s} 100 = \frac{Q_n}{v_s A_n} 100$$

SUBSTITUTING,

$$\% \; I = \frac{\frac{T_s}{P_s}\left[K_3 V_{1c} + \frac{V_m}{T_m}\left(P_b + \frac{\Delta H}{13.6}\right)\right]}{A_n \quad \theta \quad v_s} 100$$

% I FR EXPRESSION

$$\% \; I = \frac{100 \, T_s \left[V_{1c} \; K_3 + \frac{V_m}{T_m} \left(P_b + \frac{\Delta H}{13.6}\right)\right]}{60 \; \theta \, v_s P_s A_n}$$

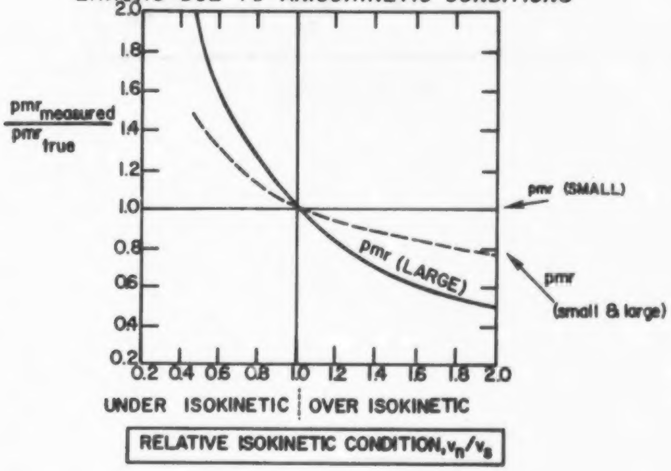
% I FR Expression
from intermediate data

$$\% I = K_4 \frac{T_s \; V_{m(std)}}{P_s \; v_s \; A_n \theta \quad (1-B_{ws})}$$

K = 0.09450
for English units

$$\overline{pmr}_s = \frac{m_n}{V_n} \; A_s \bar{v}_s$$

ERRORS DUE TO ANISOKINETIC CONDITIONS



Lecture 9

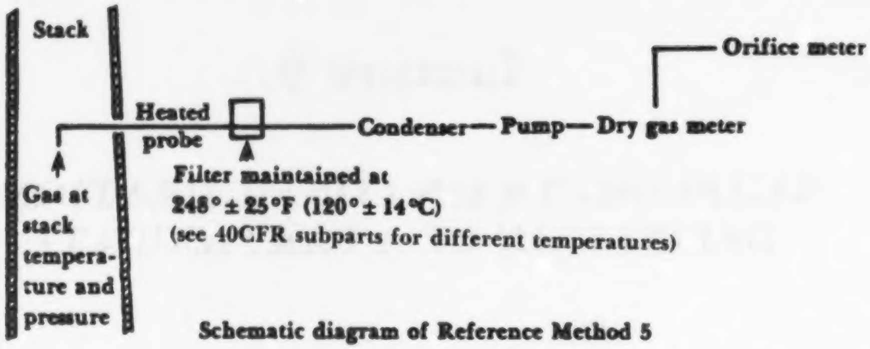
SAMPLING TRAIN CONFIGURATION: DEFINITION OF A PARTICULATE

Lesson Objectives:

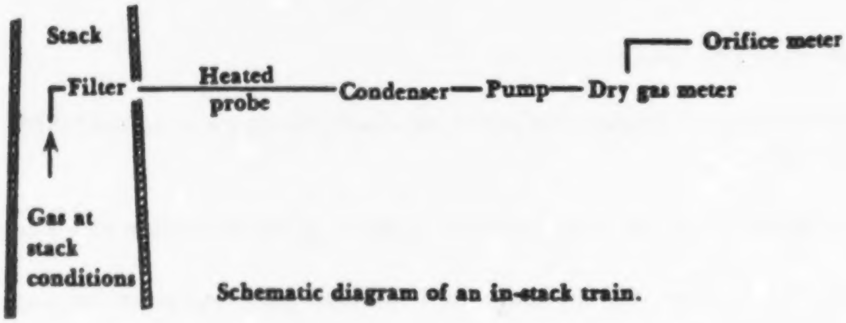
The student will be able to:

- Write the Federal Register definition of a particulate given in the NSPS regulations.
- Describe the sampling train parameters effecting the definition of a particulate.
- Define "particulate" for the sampling train configurations given on page 78 of the workbook.

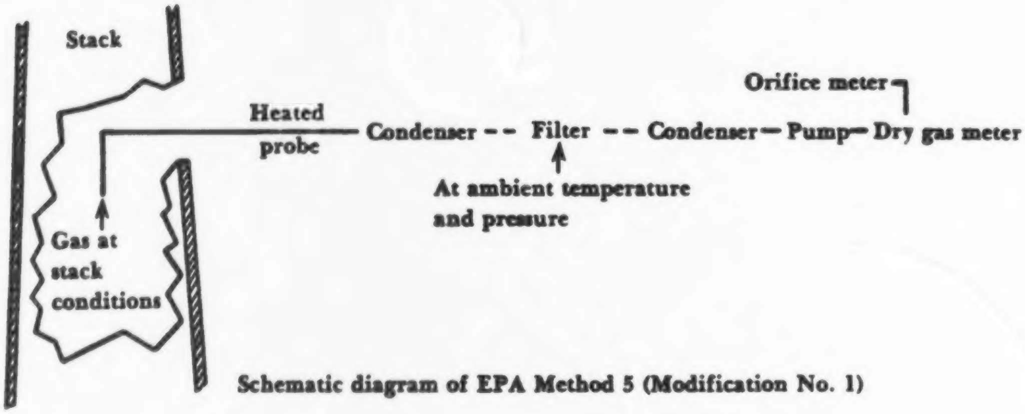
Sampling Train Configurations


Stack
Orifice meter
Heated probe
Condenser — Pump — Dry gas meter
Filter maintained at
248° ± 25°F (120° ± 14°C)
(see 40CFR subparts for different temperatures)
Gas at stack temperature and pressure

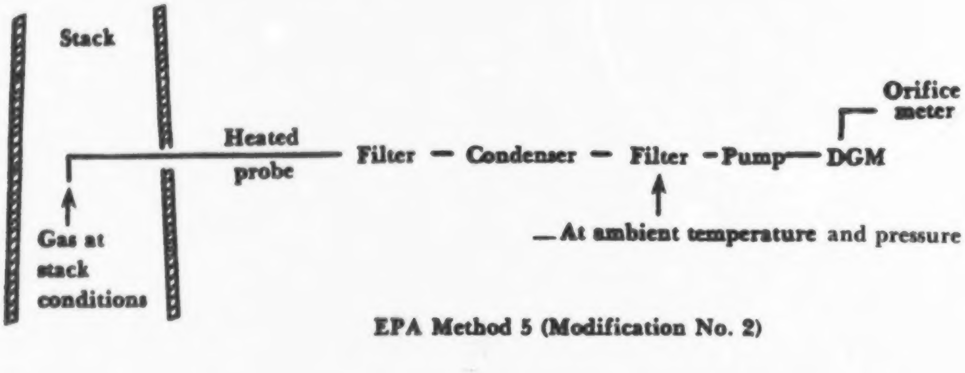
Schematic diagram of Reference Method 5



Schematic diagram of an in-stack train.


Stack
Orifice meter
Heated probe
Condenser - - Filter - - Condenser — Pump — Dry gas meter
At ambient temperature and pressure
Gas at stack conditions

Schematic diagram of EPA Method 5 (Modification No. 1)


Stack
Orifice meter
Heated probe
Filter — Condenser — Filter — Pump — DGM
— At ambient temperature and pressure
Gas at stack conditions

EPA Method 5 (Modification No. 2)

Lecture 10

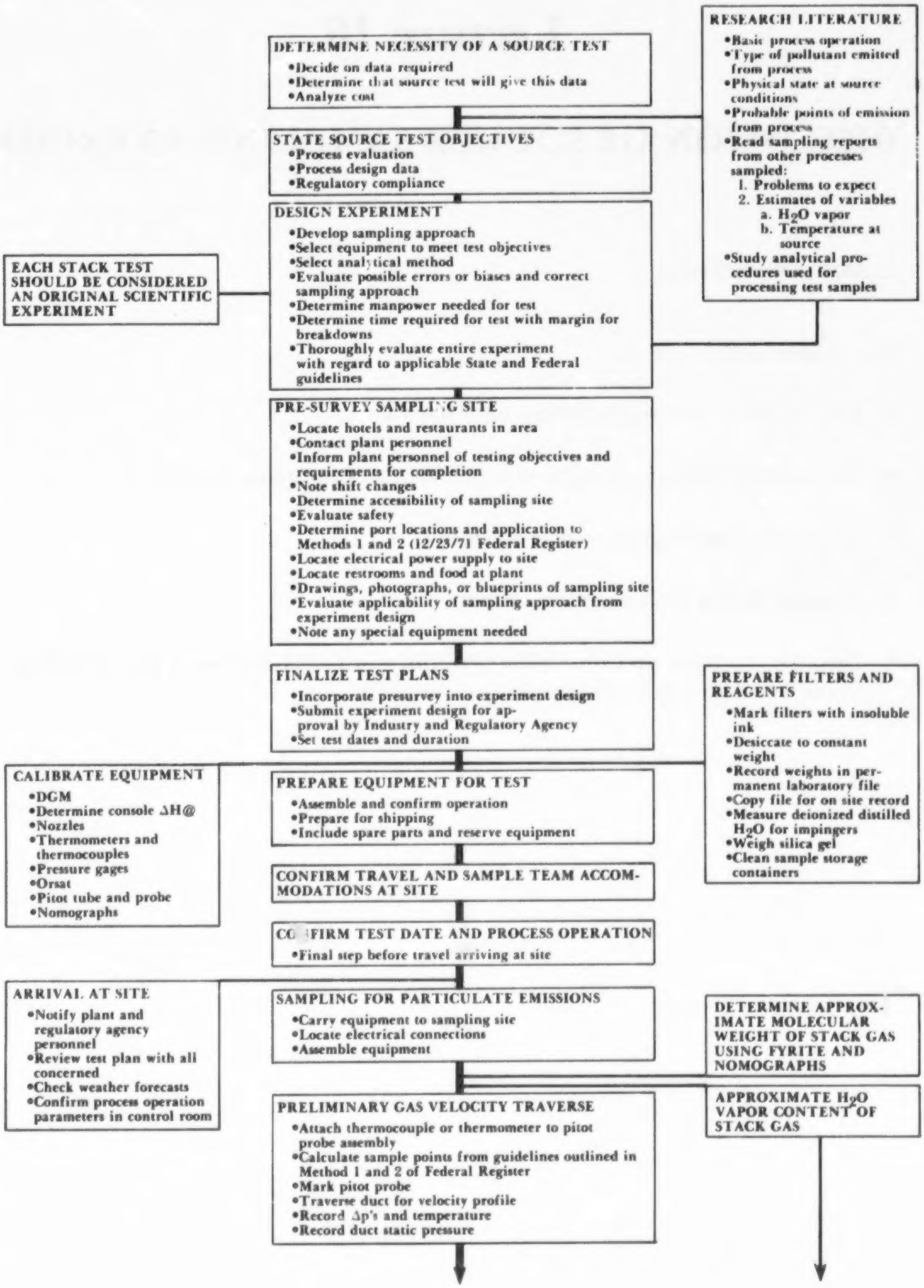
DISCUSSION OF SOURCE SAMPLING EXERCISE

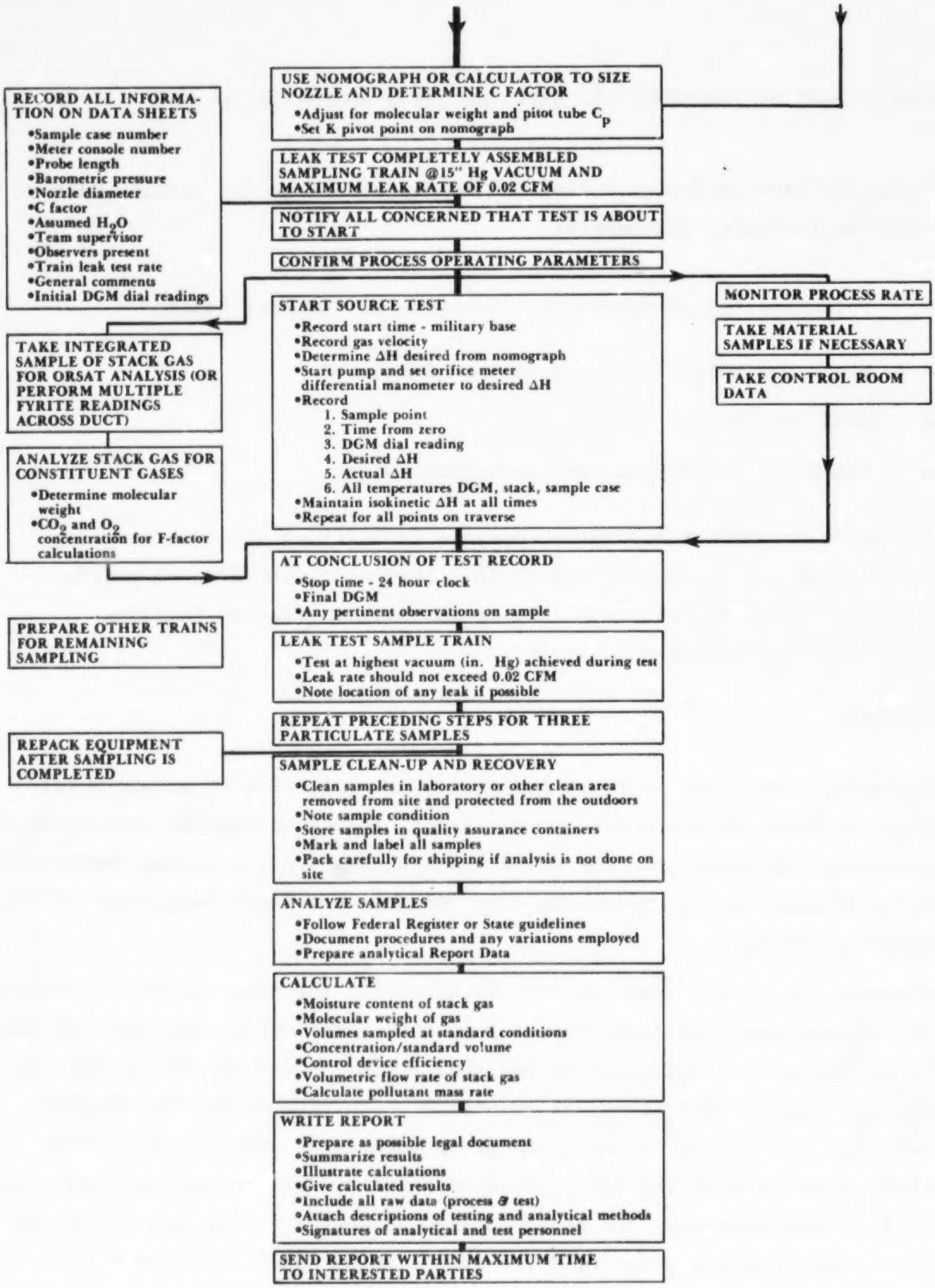
Lesson Objectives:

The student will be able to:

- List the steps involved in designing a stack test.
- List the information necesary in a pre-survey of the stack test site.
- Recall the planning steps for a stack test.
- Recall a usable report writing format.
- Describe the basic procedures for performing an EPA Method 5 test including filling out data forms and making calculations.

Planning and performing a stack test.


DETERMINE NECESSITY OF A SOURCE TEST
•Decide on data required
•Determine that source test will give this data
•Analyze cost
RESEARCH LITERATURE
•Basic process operation
•Type of pollutant emitted from process
•Physical state at source conditions
•Probable points of emission from process
•Read sampling reports from other processes sampled:
1. Problems to expect
2. Estimates of variables
a. H_2O vapor
b. Temperature at source
•Study analytical procedures used for processing test samples
STATE SOURCE TEST OBJECTIVES
•Process evaluation
•Process design data
•Regulatory compliance
EACH STACK TEST SHOULD BE CONSIDERED AN ORIGINAL SCIENTIFIC EXPERIMENT
DESIGN EXPERIMENT
•Develop sampling approach
•Select equipment to meet test objectives
•Select analytical method
•Evaluate possible errors or biases and correct sampling approach
•Determine manpower needed for test
•Determine time required for test with margin for breakdowns
•Thoroughly evaluate entire experiment with regard to applicable State and Federal guidelines
PRE-SURVEY SAMPLING SITE
•Locate hotels and restaurants in area
•Contact plant personnel
•Inform plant personnel of testing objectives and requirements for completion
•Note shift changes
•Determine accessibility of sampling site
•Evaluate safety
•Determine port locations and application to Methods 1 and 2 (12/23/71 Federal Register)
•Locate electrical power supply to site
•Locate restrooms and food at plant
•Drawings, photographs, or blueprints of sampling site
•Evaluate applicability of sampling approach from experiment design
•Note any special equipment needed
FINALIZE TEST PLANS
•Incorporate presurvey into experiment design
•Submit experiment design for approval by Industry and Regulatory Agency
•Set test dates and duration
PREPARE FILTERS AND REAGENTS
•Mark filters with insoluble ink
•Desiccate to constant weight
•Record weights in permanent laboratory file
•Copy file for on site record
•Measure deionized distilled H_2O for impingers
•Weigh silica gel
•Clean sample storage containers
CALIBRATE EQUIPMENT
•DGM
•Determine console ΔH@
•Nozzles
•Thermometers and thermocouples
•Pressure gages
•Orsat
•Pitot tube and probe
•Nomographs
PREPARE EQUIPMENT FOR TEST
•Assemble and confirm operation
•Prepare for shipping
•Include spare parts and reserve equipment
CONFIRM TRAVEL AND SAMPLE TEAM ACCOMMODATIONS AT SITE
CONFIRM TEST DATE AND PROCESS OPERATION
•Final step before travel arriving at site
ARRIVAL AT SITE
•Notify plant and regulatory agency personnel
•Review test plan with all concerned
•Check weather forecasts
•Confirm process operation parameters in control room
SAMPLING FOR PARTICULATE EMISSIONS
•Carry equipment to sampling site
•Locate electrical connections
•Assemble equipment
DETERMINE APPROXIMATE MOLECULAR WEIGHT OF STACK GAS USING FYRITE AND NOMOGRAPHS
APPROXIMATE H_2O VAPOR CONTENT OF STACK GAS
PRELIMINARY GAS VELOCITY TRAVERSE
•Attach thermocouple or thermometer to pitot probe assembly
•Calculate sample points from guidelines outlined in Method 1 and 2 of Federal Register
•Mark pitot probe
•Traverse duct for velocity profile
•Record Δp's and temperature
•Record duct static pressure


USE NOMOGRAPH OR CALCULATOR TO SIZE NOZZLE AND DETERMINE C FACTOR
•Adjust for molecular weight and pitot tube C_p
•Set K pivot point on nomograph
RECORD ALL INFORMATION ON DATA SHEETS
•Sample case number
•Meter console number
•Probe length
•Barometric pressure
•Nozzle diameter
•C factor
•Assumed H_2O
•Team supervisor
•Observers present
•Train leak test rate
•General comments
•Initial DGM dial readings
LEAK TEST COMPLETELY ASSEMBLED SAMPLING TRAIN @15" Hg VACUUM AND MAXIMUM LEAK RATE OF 0.02 CFM
NOTIFY ALL CONCERNED THAT TEST IS ABOUT TO START
CONFIRM PROCESS OPERATING PARAMETERS
MONITOR PROCESS RATE
TAKE MATERIAL SAMPLES IF NECESSARY
TAKE CONTROL ROOM DATA
START SOURCE TEST
•Record start time - military base
•Record gas velocity
•Determine ΔH desired from nomograph
•Start pump and set orifice meter differential manometer to desired ΔH
•Record
1. Sample point
2. Time from zero
3. DGM dial reading
4. Desired ΔH
5. Actual ΔH
6. All temperatures DGM, stack, sample case
•Maintain isokinetic ΔH at all times
•Repeat for all points on traverse
TAKE INTEGRATED SAMPLE OF STACK GAS FOR ORSAT ANALYSIS (OR PERFORM MULTIPLE FYRITE READINGS ACROSS DUCT)
ANALYZE STACK GAS FOR CONSTITUENT GASES
•Determine molecular weight
•CO_2 and O_2 concentration for F-factor calculations
AT CONCLUSION OF TEST RECORD
•Stop time - 24 hour clock
•Final DGM
•Any pertinent observations on sample
PREPARE OTHER TRAINS FOR REMAINING SAMPLING
LEAK TEST SAMPLE TRAIN
•Test at highest vacuum (in. Hg) achieved during test
•Leak rate should not exceed 0.02 CFM
•Note location of any leak if possible
REPEAT PRECEDING STEPS FOR THREE PARTICULATE SAMPLES
REPACK EQUIPMENT AFTER SAMPLING IS COMPLETED
SAMPLE CLEAN-UP AND RECOVERY
•Clean samples in laboratory or other clean area removed from site and protected from the outdoors
•Note sample condition
•Store samples in quality assurance containers
•Mark and label all samples
•Pack carefully for shipping if analysis is not done on site
ANALYZE SAMPLES
•Follow Federal Register or State guidelines
•Document procedures and any variations employed
•Prepare analytical Report Data
CALCULATE
•Moisture content of stack gas
•Molecular weight of gas
•Volumes sampled at standard conditions
•Concentration/standard volume
•Control device efficiency
•Volumetric flow rate of stack gas
•Calculate pollutant mass rate
WRITE REPORT
•Prepare as possible legal document
•Summarize results
•Illustrate calculations
•Give calculated results
•Include all raw data (process & test)
•Attach descriptions of testing and analytical methods
•Signatures of analytical and test personnel
SEND REPORT WITHIN MAXIMUM TIME TO INTERESTED PARTIES

I. PRELIMINARY MEASUREMENTS AND SETUP OF THE SAMPLING TRAIN

Using the data collected during the Monday afternoon lab session, determine the following parameters:

- Determination of equivalent diameter and traverse points
- Stack gas velocity and volumetric flow rate
- Moisture content of flue gas
- Stack gas temperature and molecular weight

The above parameters must be determined in order to pick the correct nozzle size and to set the nomograph. Incorrect selection of nozzle size may result in not being able to maintain isokinetic sampling rate, thereby voiding the sample.

II. SAMPLING

The on-site sampling includes making a final selection of proper nozzle size, setting the nomograph or calculator, making an initial leak-check, inserting the probe into the stack, sealing the port, sampling isokinetically while traversing, recording the data and making a final leak-check of the sampling system.

However, due to the sampling port locations in the test section, cooperation is required with the group directly located across from your own test port. Referring back to Figure 3, we see that ports 1 and 2 of each module lie on the same centerline. Thus, in order for a traverse to be done without interfering with one another, the group located at port 1 should start their traverse with the first traverse point closest to the facility inside wall. Simultaneously, the group located at port 2 should start with the furtherest traverse point from the inside wall. Thus, while one group is traversing toward the opposite wall, the other group is returning to that wall.

III. SOURCE TEST

Good organization of the sampling team will make the source test much easier, save time and improve the quality of the data. Each sample team member should have a specific task at the site. The flow chart provided is a brief outline of procedures. The entire experiment is outlined in the two-part flow chart you have received. The procedures involved are described below.

Description of Procedures

A. Assemble the Sampling Train

1. Inspect the sampling nozzle

   - The nozzle should be perfectly round and of uniform diameter throughout. Any out-of-round nozzles should be rounded or replaced.
   - The round nozzle diameter should be precisely measured with a micrometer to three decimal places.

2. Inspect the sampling probe*

   - Remove swagelock union and determine the presence of asbestos string ($T_s > 350^oF$) or rubber o-ring seals and a compression seal spacer.
   - Inspect the end of the probe glass liner for cracks and chips.
   - Make certain a small diameter hole is drilled in the probe sheath (allows pressure equalization)
   - Remove the liner and check the glass liner heater connections for frayed wires.
   - Inspect the condition, alignment, and attachment of the pitot tube.
   - Reassemble and position in sample case.

   *NOTE: These steps have already been done for you. They are included here for you to follow when you are on your own.

3. Sample Case

- Check the thermometers
- Inspect the electrical connections for the umbilical cord, probe, and filter heater.
- Be certain the sampling probe attachment is in proper order for the sampling.
- Close ice compartment drain plug.

4. Glassware*

- Be sure the glass impingers are clean
- Grease all joint surfaces-for the ball joint type glassware - inspecting all pieces for cracks or chips.
- Fill the impingers:
    1. Measure 100 ml of distilled water into each of the first two impingers.
    2. The third impinger is left empty.
    3. Place approximately 200 g of preweighted indicating silica gel into the fourth impinger.

The first, third and fourth impingers are modified Greenburg-Smith while the second impinger is a standard Greenburg-Smith design. Place the impingers into the sampling box and assemble the sampling train using the appropriate U-tubes.

*NOTE: These steps have been done prior to laboratory exercise.

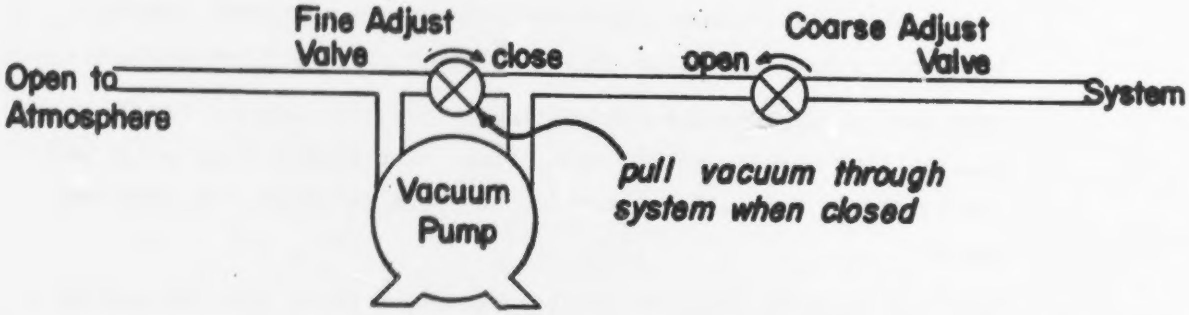
5. Load Filter

- The preweighed filter is removed from its sealed container and placed in the filter holder. Make sure that the filter is centered correctly in the holder with the sample side toward the probe. The filter holder should be tightened until the two halves are secure.
- Attach the probe to the filter holder, being sure not to apply excessive torque to the glass components.

B. Leak Test the Assembled Sampling Train

1. Test the completely assembled sampling train at 15in. on the Vacuum Gage.

   - Be certain the valves on the RAC Meter Console are "out"
   - Turn on the console pump
   - Turn on probe heater and filter box temperature switches, allow to reach operating temperature.
   - Turn fine adjust valve fully counter-clockwise
   - Seal nozzle opening with duct tape or rubber stopper
   - Open coarse adjust valve slowly until fully counter-clockwise
   - Slowly turn fine adjust valve clockwise until vacuum reaches 15" Hg. on gage. If you over shoot 15" Hg. do not turn fine adjust valve back, simply read and record at vacuum on gage.



   - Note DGM dial pointer. If the pointer does not move for 15 seconds the leak test is good. If it continues to move, time the leak using a stopwatch. 0.02CFM is the maximum acceptable leak rate
   - Any leak greater than 0.02CFM must be prevented.
   - Slowly release vacuum at the nozzle before closing coarse adjust valve.

2. Track down any leaks by successive back tracking leak checks--Disconnect filter and test the system back from the first impinger, etc.

3. Record the leak rate

C. Calculate Sampling Points on Traverse Following Method 1 Guidelines and Mark Probe From Center of Pitot Orifice Back to Sample Case. Set up nomograph and calculators.

1. Use the data from the Monday laboratory for stack temperature and average Δp.
2. Each laboratory group is to set up at least one calculator and at least one nomograph in order to obtain ΔH values.

D. Fill Out Data Sheets

1. Label time intervals for each sampling point
2. Record the initial DGM reading
3. Fill out all data blanks

E. Isokinetic Sampling

1. Place ice in the condenser section of the sampling train. Turn on the probe heater and filter box temperature switches. Check to insure proper operation. Allow to reach operating temperature.
2. Fill out the appropriate information on the "Particulate Data" sheet. This should include date, time, test time at each point and DGM reading. Once all information has been recorded, the test can begin.
3. Move the sampling train to the first traverse point with the nozzle pointing directly into the gas stream. Seal the port and immediately start the pump, noting time and DGM reading.
   - Determine and calculate the proper ΔH using the calculator or nomograph. Check to see that the nomograph and calculator values agree.
   - Adjust ΔH using coarse and fine valve.
   - Maintain isokinetic conditions during the entire sampling period by observing Δp and setting ΔH through the use of the nomograph or calculator. Adjust the sampling rate at each traverse point by adjusting the coarse and fine valves. When significant changes in stack conditions are observed, compensating adjustments in flow rate should be made. Three conditions would account for realigning nomograph or calculator:

1. Stack gas temperature varies by more than 25°F.
2. t_m (average temperature of meter) varies by more than 11°F.
3. Significant changes in moisture content (B_{ws}).

- At each traverse point, the following information should be observed and recorded on the field data sheet: stack temperature (t_s), velocity pressure head (Δp), orifice pressure differential (ΔH), gas temperature at dry gas meter ($t_{m_{avg}}$), sample box temperature, condenser temperature and probe temperature. The time period at each traverse point must be long enough to obtain a total sampling period representative of the process being monitored. The time at each traverse point must be sufficient to obtain a total sample volume of at least 30 DSCF.

  Fifteen seconds before the end of sampling at the first traverse point, move the probe and sample container assembly to the next point. Allow a short time period to stabilize the Δp reading. Adjust ΔH to the corresponding isokinetic rate and record on data sheet. Repeat this procedure for each additional traverse point.

F. Test Completion

1. At the completion of the test, close the coarse control valve on the meter, remove the probe from the stack and turn off the pump. Remove the probe carefully from the stack to insure that the nozzle does not scrape dust from the inside of the port. Seal the port. Keep the probe elevated to insure loss of sample does not occur. Record all proper information on the field log sheet. This should include final DGM reading, stop time, probe temperature and meter box temperature.
2. Perform a post leak check on the sample train following the same procedure as in the pretest. Record final leak rate on data sheet.

G. Sample Recovery

1. Disassemble sampling train
   - Disassemble filter holder and seal until ready to clean
   - When probe has reached ambient temperature, seal at both ends until ready to clean.

IV. ANALYTICAL RECOVERY

During sample recovery, care must be taken to prevent loss or contamination of the sample.

- Filter Holder - Care must be taken when removing the filter from its holder. Be sure that extraneous dirt does not become a part of the sampling run. Place the filter into its original container, seal, label and record filter number on the data sheet.
- Silica Gel - Transfer the silica gel from the fourth impinger to its original preweighed container. The use of a funnel to transfer the silica gel would be most helpful. Once it has been transfered, label and seal properly.
- Condenser - Measure the total volume of condensation (± 1 ml) transferring the contents of the first three impingers into a graduated cylinder. Record on the data log sheet.
- Acetone Wash-Front Half - Wash all internal surfaces of the sampling train from the nozzle tip up to the backside of the filter holder with acetone. Determine the volume to the nearest ml and transfer to a labeled container. A brush with a handle as long as the probe may be used to dislodge particulate matter from the inside of the probe. Include this with the acetone washings.

V. ANALYTICAL ANALYSIS

Record the necessary data on the "Laboratory Analysis Data" sheet concerning sample identification and sample integrity. Proper procedure indicates desiccating both for 24 hours in a desiccator, then weighing to a constant weight. However, the time period for this course is restrictive, therefore, weigh the filter without desiccating. For proper analysis, please refer to The Federal Register, Vol. 42, No. 160, August 18, 1977.

- Silica Gel - Weigh the spent silica gel to the nearest 0.5g using a balance. Record the final weight on the "Data" sheet.
- Filter - Weight the filter to the nearest 0.1 mg using a balance. Record the final weight on the "Data sheet".
- Probe Wash - Submit your probe wash to the instructor. He will evaporate the sample and have it weighed for you. The data will be supplied to you Thursday morning.

VI. CALCULATIONS

Complete the "Source Test Data Summary" worksheet found in the workbook. This should include information obtained during Monday's and Wednesday's laboratory sessions.

Note: It will be necessary to defer the calculation of C_s, pmr, and E, the Emission Rate, until after you have received the weight of the particulate contribution from the nozzle and probe. The instructor will provide this data to you Thursday morning.

Particulate Field Data

Very Important—Fill in all Blanks

Plant ____
Run no. ____
Location ____
Date ____
Operator ____
Sample box no. ____
Meter box no. ____
Nomograph ID no. ____
Orsat no. ____ Date rebuilt ____
Fyrite no. ____ Date rebuilt ____

C_p ____
$\Delta H_@$ ____
P_m, in. Hg ____
P_s in. Hg ____
B_{ws} (assumed) ____
M_d ____
M_s ____
T_m, °R ____
T_s, °R ____
$\Delta p_{avg.}$, in. H_20 ____

Test start time ____
Stop time ____
D_n calculated (in.) ____
D_n, used (in.) ____
Ambient temp., °F ____
Bar. pressure, in. Hg ____
Heater box setting, °F ____
Probe heater setting, °F ____
Average ΔH ____
Leak rate@15 in. Hg Pre-test ____ Post-test ____

Point	Clock time (min)	Dry gas meter CF	Pitot in H_2O Δp	Orifice ΔH in H_2O		Dry gas temp. °F		Pump vacuum in. Hg gauge	Box temp. °F	Impinger temp. °F	Stack press. in. Hg	Stack temp. °F	Fyrite %CO_2
				Desired	Actual	Inlet	Outlet						

Comments: ____

Test observers: ____ ____

continued

Point	Clock time (min)	Dry gas meter CF	Pitot in H_2O Δp	Orifice ΔH in H_2O		Dry gas temp. °F		Pump vacuum in. Hg gauge	Box temp. °F	Impinger temp. °F	Stack press. in. Hg	Stack temp. °F	Fyrite $\%CO_2$
				Desired	Actual	Inlet	Outlet						

Comments: ____

____

Test observers: ____________________ ____________________

Name ______________________________
Group No. ___________________________

SOURCE TEST DATA SUMMARY

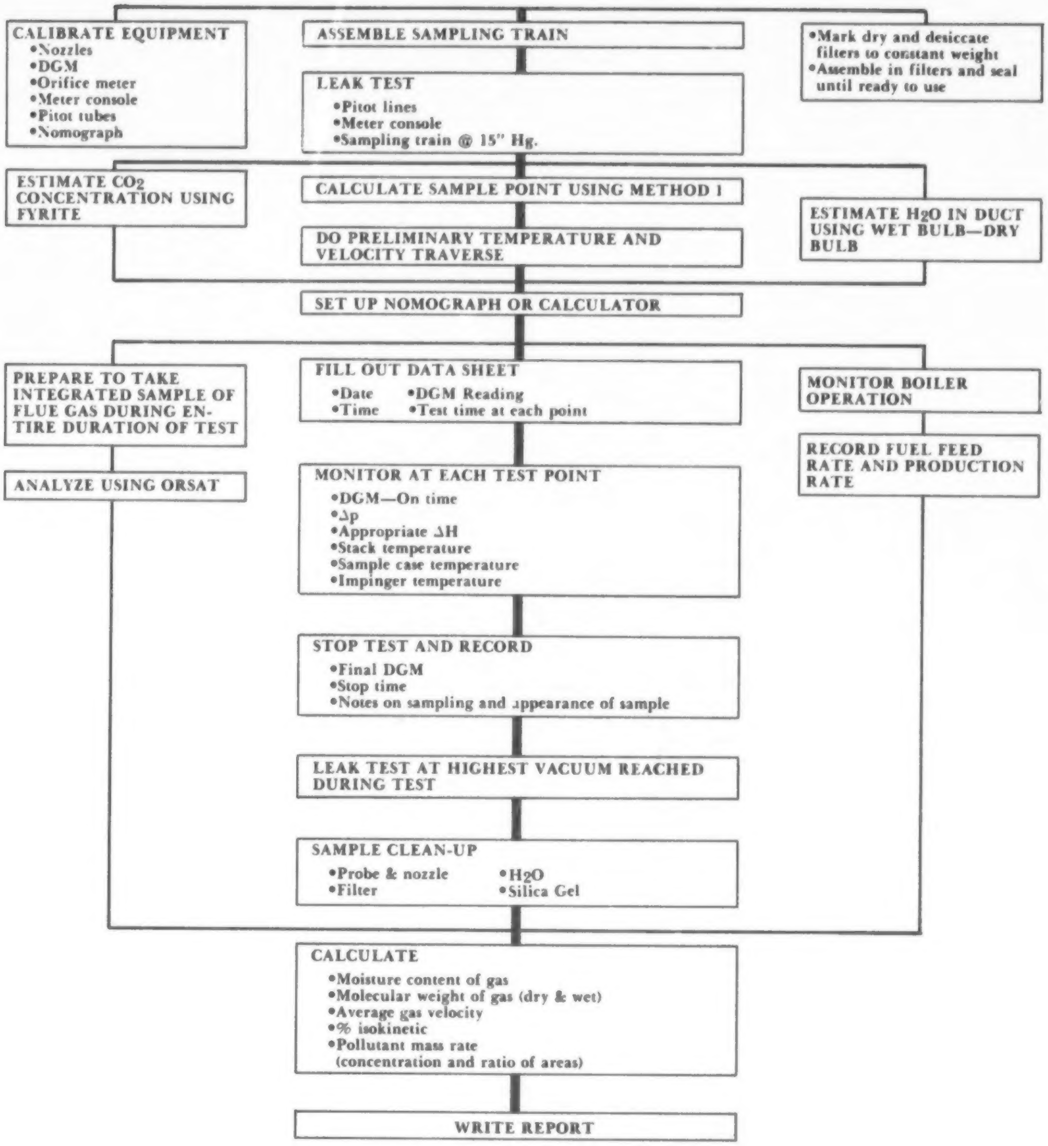
1. Total number of sampling points __________
2. Total test time __________ minutes
3. Stack cross-sectional area __________ sq. ft.
4. Orsat analysis
    - %CO_2 __________
    - %O_2 __________
    - %N_2 __________
    - B_{ws} __________
    - M_d __________ lb/lb-mole
    - M_s __________ lb/lb-mole
5. Average stack gas temperature __________ °F + 460 = __________ °R
6. Barometric pressure (P_b) ______________________ in. Hg
7. Absolute stack pressure (P_s) ______________________ in. Hg
8. Stack gas velocity data
    - Pitot tube C_p = __________
    - Average Δp __________ in. H_2O
    - Average velocity (v_s) __________________ ft/sec
9. Average stack gas dry standard volumetric flow rate (Q_s) __________ DSCFH
10. Sampling nozzle diameter __________________ inches
11. Particulate catch weight ______________________ mg
12. Meter console volume
    - Volume metered (V_m) ____________________ CF
    - Standard volume metered (V_{mstd}) ________________ DSCF
13. Particulate concentration (c_s) __________________ grains/ DSCF
14. %Isokinetic __________________
15. Pollutant mass rate at standard conditions ______________ lb/hr
16. Emission rate __________________________ lb/10^6Btu
    (Use F-factor for propane)

Name ______________________________
Group No. ____________________________

SOURCE TEST DATA SUMMARY

1. Total number of sampling points __________
2. Total test time __________ minutes
3. Stack cross-sectional area __________ sq. ft.
4. Orsat analysis
    - %CO_2 __________
    - %O_2 __________
    - %N_2 __________
    - B_{ws} __________
    - M_d __________ lb/lb-mole
    - M_s __________ lb/lb-mole
5. Average stack gas temperature __________ °F + 460 = __________ °R
6. Barometric pressure (P_b)______________________in. Hg
7. Absolute stack pressure (P_s) ____________________in. Hg
8. Stack gas velocity data
    - Pitot tube C_p = __________
    - Average Δp __________ in. H_2O
    - Average velocity (v_s) ________________ft/sec
9. Average stack gas dry standard volumetric flow rate (Q_s) ____________DSCFH
10. Sampling nozzle diameter __________________inches
11. Particulate catch weight ____________________mg
12. Meter console volume
    - Volume metered (V_m) __________________CF
    - Standard volume metered (V_{mstd})______________DSCF
13. Particulate concentration (c_s) __________________grains/ DSCF
14. %Isokinetic________________
15. Pollutant mass rate at standard conditions ____________lb/hr
16. Emission rate________________________lb/10^6Btu
    (Use F-factor for propane)

Source test outline.


CALIBRATE EQUIPMENT
•Nozzles
•DGM
•Orifice meter
•Meter console
•Pitot tubes
•Nomograph
ASSEMBLE SAMPLING TRAIN
•Mark dry and desiccate filters to constant weight
•Assemble in filters and seal until ready to use
LEAK TEST
•Pitot lines
•Meter console
•Sampling train @ 15" Hg.
ESTIMATE CO2 CONCENTRATION USING FYRITE
CALCULATE SAMPLE POINT USING METHOD 1
ESTIMATE H2O IN DUCT USING WET BULB—DRY BULB
DO PRELIMINARY TEMPERATURE AND VELOCITY TRAVERSE
SET UP NOMOGRAPH OR CALCULATOR
PREPARE TO TAKE INTEGRATED SAMPLE OF FLUE GAS DURING ENTIRE DURATION OF TEST
FILL OUT DATA SHEET
•Date
•Time
•DGM Reading
•Test time at each point
MONITOR BOILER OPERATION
ANALYZE USING ORSAT
RECORD FUEL FEED RATE AND PRODUCTION RATE
MONITOR AT EACH TEST POINT
•DGM—On time
•Δp
•Appropriate ΔH
•Stack temperature
•Sample case temperature
•Impinger temperature
STOP TEST AND RECORD
•Final DGM
•Stop time
•Notes on sampling and appearance of sample
LEAK TEST AT HIGHEST VACUUM REACHED DURING TEST
SAMPLE CLEAN-UP
•Probe & nozzle
•Filter
•H2O
•Silica Gel
CALCULATE
•Moisture content of gas
•Molecular weight of gas (dry & wet)
•Average gas velocity
•% isokinetic
•Pollutant mass rate (concentration and ratio of areas)
WRITE REPORT

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Lecture 11

CONCENTRATION CORRECTION AND PROBLEM SESSION

Lesson Objectives:

The student will be able to:

- Discuss the relationships that exist in fossil fuel-fired boilers between excess air, % O_2, and % CO_2.
- Define excess air.
- Correct a particulate concentration to standard temperature and pressure.
- Correct a particulate concentration to 50% excess air using two methods.
- Correct a particulate concentration to 12% CO_2.
- Correct a particulate concentration to 6% O_2.

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I. CONCENTRATION CORRECTION

CONCENTRATION CORRECTION

$$c_{s_{corr}} = c_s \frac{P_{std}\, T_s}{P_s T_{std}}$$

% EXCESS AIR

$$\%\ EA. = \frac{\text{Volume Excess Air}}{\text{Theoretical Volume required for complete combustion}} \quad X\ 100$$

$$\%\ EA. = \frac{\%\ O_2 - .5(\%\ CO)}{.264(\%\ N_2) - [\%\ O_2 - .5(\%\ CO)]}\ X\ 100$$

50% Excess Air Correction for C_s

Given % EA

$$c_{s50} = \frac{c_s\ [100 + \%\ EA]}{150}$$

50% Excess Air Correction from Orsat Data

$$c_{s50} = \frac{c_s}{1 - \left[\dfrac{1.5(\%O_2) - .133(\%N_2) - .75(\%CO)}{21}\right]}$$

CORRECTING CONCENTRATION
to 12% CO_2

$$c_{s12} = c_s \frac{12}{\% CO_2}$$

CORRECTING CONCENTRATION TO 6% OXYGEN

$$c_{s6\%\,O_2} = \frac{c_s\,(20.9 - 6.0)}{20.9 - \%\,O_2}$$

II. PROBLEM SESSION

Several problems are presented to help in understanding the use of these concentration corrections and give you practice. Examples of the calculations are given in Problem I.

Problem I

Source tests were performed at a facility burning residual oil on two different occasions. The fuel feed rate was 10 gallons oil/Hr. for both tests, however, the % Excess Air varied to insure good combustion. Given the following Test data calculate the corrected pollutant concentration in grains (gr /ft ^{3}) for each condition shown in the table provided.

Test Number	% EA	Orsat Analysis				Q_s DSCF/min	PMR gr /min	c_s gr /DSCF	$\bar{C}_{s_{12}}$	$c_{s_{50}}$	
		%CO_2	%O_2	%CO	%N_2					From	
										% EA	Raw Orsat Data
1A	10	13.3	2.2	0	84.5	14,300	10,000				
1B		9.7	7.1	0.2	83.0	19,400	10,000				

Example Calculations

Test Number 1A

1. Average pollutant concentration (c_s)

$$c_s = \frac{PMR}{\bar{Q}_s} = \frac{1 \times 10^4 \text{ gr /min}}{1.43 \times 10^4 \text{ DSCF/min}} = 0.699 \text{gr /DSCF}$$

2. Average pollutant concentration corrected to 12% CO_2 in duct gas ($c_{s_{12}}$)

$$c_{s_{12}} = c_s \frac{12}{\%CO_2} = 0.699\text{gr /DSCF} \frac{12}{13.3} = 0.631\text{gr /DSCF}$$

3. Average pollutant concentration corrected to 50% EA ($c_{s_{50}}$)

a. Using known % EA

$$c_{s_{50}} = c_s \frac{100 + \%\ EA}{150} = 0.699\text{gr /DSCF} \frac{100 + 10}{150} = 0.513\text{gr /DSCF}$$

b. Using raw orsat data

$$c_{s_{50}} = \frac{c_s}{1 - \dfrac{1.5(\%O_2) - 0.133\ (\%N_2) - 0.75\ (\%CO)}{21}}$$

$$c_{s_{50}} = \frac{0.699\text{gr /DSCF}}{1 - \dfrac{1.5\ (2.2) - 0.133\ (84.3) - 0.75(0)}{21}} = 0.507\text{gr /DSCF}$$

Record the data calculated in the examples then calculate concentrations for Test 1B.

Problem II

A coal fired boiler burns coal at a rate of 100 lb/Hr. Two source tests at the facility yielded the following data. Make all calculations and complete the Table.

Test Number	% EA	Orsat Analysis				Q_s DSCF/min	PMR gr /min	c_s gr /DSCF	$\bar{c}_{s_{12}}$	$c_{s_{50}}$ From	
		$\%CO_2$	$\%O_2$	$\%CO$	$\%N_2$					% EA	Raw Orsat Data
2A		12.1	7.1	0.3	80.5	18,000	13,000				
2B	100	9.1	10.6	0	80.3	24,000	13,000				

Lecture 12

LITERATURE SOURCES

Lesson Objectives:

The student will be able to:

- Recall at least three types of sources from which information on source sampling methodology may be found (books, periodicals, newsletters, EPA publications).
- List the most important periodicals and professional organizations that transmit source sampling information.
- Tell how to receive assistance in obtaining EPA publications; and computerized literature searches.

LITERATURE SOURCES

A. Books

B. Periodicals

C. EPA Publications

D. Newsletters

E. Others.

Lecture 13

THE F-FACTOR METHOD

Lesson Objectives:

The student will be able to:

- Define the F-factor used in EPA Method 5 calculations.
- Discuss how the F-factor can give a value for the emission rate.
- Describe the requirements for using the F-factor in the EPA Method 5 test for new FFFSGs.
- Recall alternate F-factor methods.
- Use F-factors for cross-checking Orsat and combustion data.

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$$F_d = \frac{\text{Volume of theoretical dry combustion product burned/lb}}{10^6\ \text{Btu/lb Heating value of fuel combusted}}$$

$$E = c_s F_d \left[\frac{20.9}{20.9 - \%\,O_2} \right]$$

F FACTORS FOR VARIOUS FUELS

FUEL TYPE	F_d dscf/10^6 Btu	F_c scf/10^6 Btu	F_w wscf/10^6 Btu	F_o
BITUMINOUS COAL	9820	1810	10680	1.140
OIL	9220	1430	10360	1.3461
NATURAL GAS	8740	1040	10650	1.79
WOOD	9280	1840	—	1.5

$$F_c = \frac{\text{Volume of theoretical } CO_2 \text{ generated by combustion / lb}}{10^6\ \text{Btu/lb heating value of fuel combusted}}$$

F_c FACTOR METHOD

$$E = c_s F_c \left(\frac{100}{\% CO_2}\right)$$

Alternate F Factor Method
using wet basis data

$$E = c_{ws} F_d \left[\frac{20.9}{20.9\,(1-B_{ws})-\%O_{2_w}}\right]$$

B_{ws} = fractional moisture content of stack gas

Wet F Factor Method

F_w

$$E = c_{ws} F_w \left[\frac{20.9}{20.9\,(1-B_{wa})-\%O_{2_w}}\right]$$

B_{wa} = fractional moisture content in air

Use of F factors for cross checks

$$F_{d(calc)} = \frac{Q_{sd}}{Q_H}\left(\frac{20.9-\%\,O_2}{20.9}\right)$$

$$F_{w(calc)} = \frac{Q_{sw}}{Q_H}\left[\frac{20.9(1-B_{wa})-\%\,O_{2_w}}{20.9}\right]$$

$$F_{c(calc)} = \frac{Q_{sw}}{Q_H}\left(\frac{\%CO_{2_w}}{100}\right)$$

F_o factor

$$F_o = \frac{20.9\,F_d}{100\,F_c}$$

$$F_o = \frac{20.9-\%\,O_{2_d}}{\%\,CO_{2_d}}$$

Correcting for Incomplete Combustion

$$(\%\,CO_2)_{adj} = \%\,CO_2 + \%\,CO$$

$$(\%\,O_2)_{adj} = \%\,O_2 - .5(\%CO)$$

Lecture 14

CALCULATION REVIEW

Lesson Objectives:

The student will be able to:

- List the clean-up procedures for the RM5 sampling train.
- Make all calculations for an RM5 stack test.
- Distinguish the difference between sampling precision and sampling accuracy.
- Answer all questions on the pre-test.

Class Data Summary

Group	No. sample pt.	Time min.	A_s ft^2	A_n ft^2	B_{ws}	M_s lb/lb-mole	P_s in. Hg	v_s ft/sec	Q_s DSCFH	V_m std	%I	c_s gr/ft^3	PMR lb/hr	E lbs/10^6Btu
1														
2														
3														
4														
5														
6														
7														
8														

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Lecture 15

ERROR ANALYSIS

Lesson Objectives:

The student will be able to:

- Explain the difference between precision and accuracy.
- List and describe three categories of error. (systematic, random, illegitimate)
- Discuss the relative precision of EPA reference methods 2-5.
- Use the concepts of this lecture and not missapply the terminology in discussions of source sampling results.

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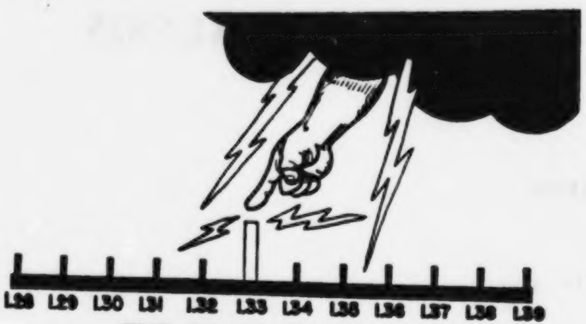
ERROR
ANALYSIS

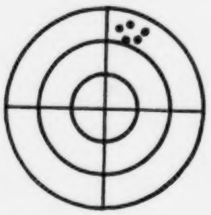


THE TRUE VALUE

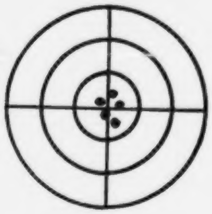
PRECISION AND ACCURACY

Precision refers to Reproducibility

Accuracy refers to Correctness



A PRECISION IS GOOD BUT ACCURACY IS POOR



B BOTH PRECISION AND ACCURACY ARE GOOD

1 *SYSTEMATIC ERRORS*
2 *RANDOM ERRORS*
3 *ILLEGITIMATE ERRORS*

Lecture 16

SOURCE SAMPLING QUALITY ASSURANCE AND SAFETY ON SITE

Lesson Objectives:

The student will be able to:

- Recall the important aspects of an accident analysis program.
- List the 10 causes of accidents.
- List some personal safety equipment for a source sampler.
- List the important items necessary to assure good quality test data.

QUALITY ASSURANCE CHECK LIST

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________
7. ______________________________
8. ______________________________
9. ______________________________
10. ______________________________
11. ______________________________
12. ______________________________
13. ______________________________
14. ______________________________
15. ______________________________
16. ______________________________
17. ______________________________
18. ______________________________
19. ______________________________
20. ______________________________

CAUSES OF ACCIDENTS

1. Poor instructions
2. Poor planning
3. Improper design
4. Proper equipment not provided
5. Failure to follow instructions
6. Neglect or improper use of equipment
7. Faulty equipment
8. Untrained personnel
9. Uncooperative personnel
10. Unpredictable outside agents

Lecture 17

PARTICULATE SIZING USING A CASCADE IMPACTOR

Lesson Objectives:

The student will be able to:

- Describe the equation of continuity for a flowing ideal fluid.
- List several particle properties and give the most important property.
- Define effective particle size.
- Define particle aerodynamic diameter.
- Describe the relationship between particle diameter and its physical properties.
- List several methods of determining particle diameter other than inertial sizing.
- Recognize the importance of a cascade impactor.
- Define the D_{50} for an impactor collection stage.
- Describe the sampling procedures used for an in-stack cascade impactor.

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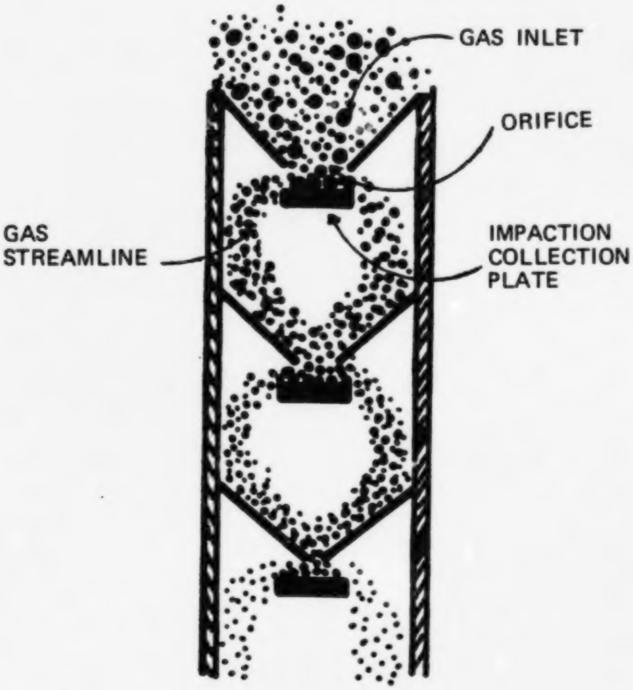
NOTES:

INERTIAL PARTICLE COLLECTOR



Lecture 18

TRANSMISSOMETERS

Lesson Objectives:

The student will be able to:

- Define the terms opacity, transmittance, and transmissometer.
- Express the relationship between opacity and transmittance.
- Recognize the proper expression for optical density.
- Discuss the EPA requirements for the design and performance of transmissometers placed on sources regulated by NSPS.
- Define the meaning of photopic and give at least two reasons why light in the photopic region is to be used in transmissometer design.
- Explain that optical density is proportional to grain loading and discuss the advantages and limitations of correlating optical density to grain loading.
- List several uses of opacity monitors.

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OPACITY IS THE PERCENTAGE OF VISIBLE LIGHT ATTENUATED DUE TO THE ABSORPTION AND SCATTERING OF LIGHT BY PARTICULATE MATTER IN FLUE GAS.

% OPACITY = 100% – % TRANSMITTANCE

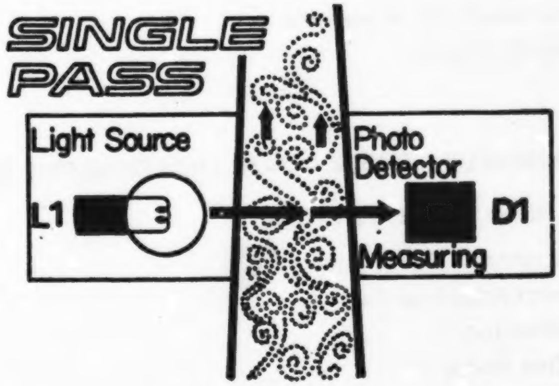
BEER · BOUGERT RELATIONSHIP

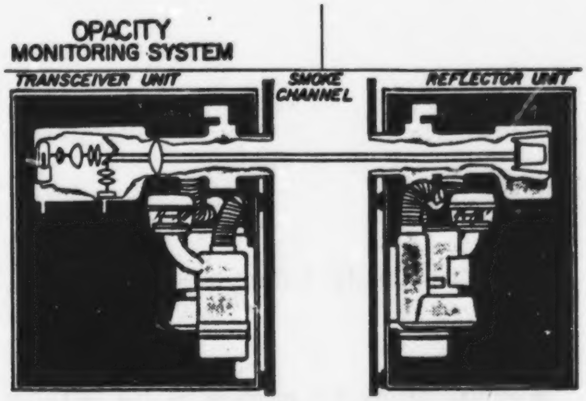
$$T = e^{-naql}$$

T = Fraction of light transmitted (Transmittance)
n = Number of particles per unit volume
a = Mean particle projected area
q = Particle extinction coefficient
l = Length of effluent path
e = Base of natural logarithm

$$\text{Optical Density} = \log_{10} \frac{1}{1 - \text{Opacity}}$$

- Optical density is a measure of the ability of an aerosol to attenuate light.
- Optical density is proportional to both path length and particulate concentration.





VENDORS OF SINGLE – PASS TRANSMISSOMETERS

Cost Range $800 - $ 4,000

Bailey Meter
Cleveland Controls, Inc.
De - Tec - Tronic Corp.
Reliance Instrument Manufacturing
HABCO
Leeds & Northrop
Photomation, Inc.
Preferred Utilities Manufacturing
Electronics Corp. of America
Robert H. Wagner

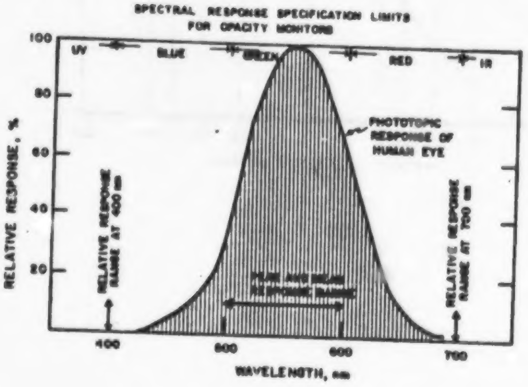
VENDORS OF DOUBLE – PASS TRANSMISSOMETERS

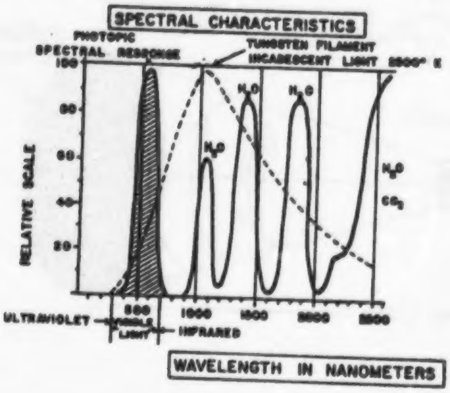
Cost Range $8,000 – $ 16,000

Environmental Data Corp.
Research Appliance Co.
Dynatron Inc.
Esterline Angus
Lear Siegler
Contraves - Goerz Corp.
Datatest, Inc.
Anderson - 2000

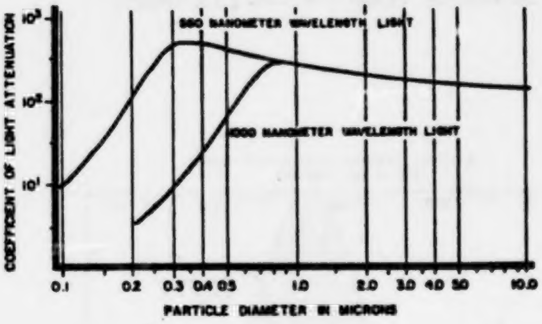
OPACITY MONITOR SPECIFICATIONS

SPECTRAL RESPONSE ——— PHOTOPIC
ANGLE OF VIEW ——— 5%
ANGLE OF PROJECTION ——— 5%
CALIBRATION ERROR ——— ≤3% OPACITY

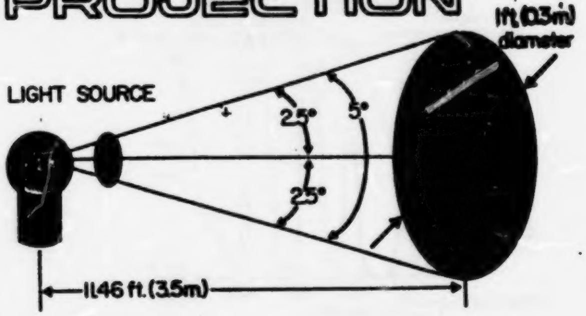


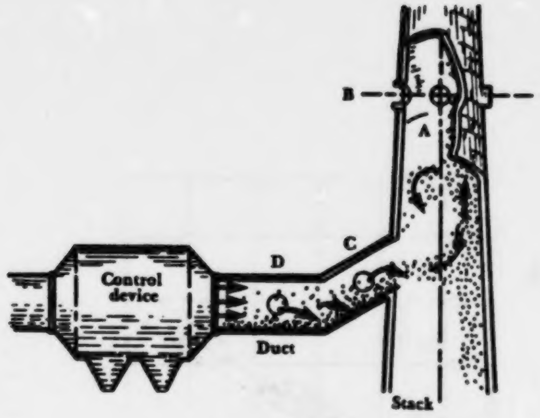


PARTICLE SIZE EFFECTS



ANGLE OF PROJECTION



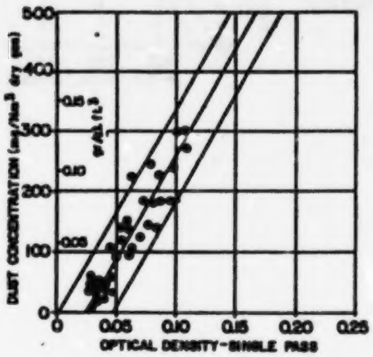


TRANSMISSOMETER APPLICATIONS

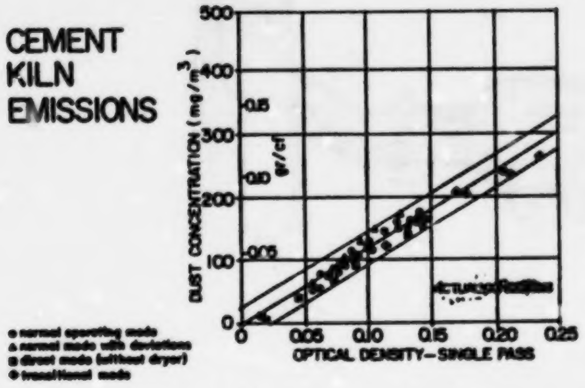
1. Installation to satisfy EPA continuous opacity monitoring requirements.
2. Installation for process performance data - - maintenance and repair indicator, process improvement
3. Installation for control equipment operation - - ESP tuning, broken bag detector.
4. Correlation with particulate concentration.
5. Maintenance of a continuous emissions record.

LIGNITE
FIRED
BOILER
EMISSIONS

(standard
conditions)

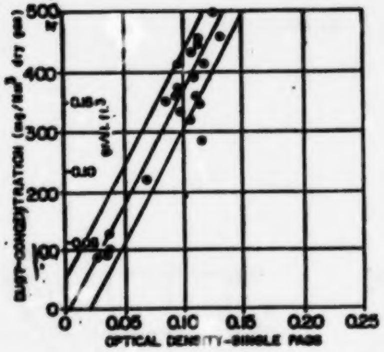


CEMENT
KILN
EMISSIONS



BITUMINOUS
COAL FIRED
BOILER
EMISSIONS

(standard
conditions)



Appendix

Appendix A

Sample Data Sheets

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METHOD 5—SOURCE TEST DATA SHEETS

Preliminary Survey—Source Sampling Site

Date ______ Survey investigator ______
Plant name ______ City ______ State ______
Previous test(s) by: ______ Reports available ______
Plant contacts ______ Title ______ Phone ______
______ Title ______ Phone ______
______ Title ______ Phone ______
Complete directions to plant from point of origin ______
______
______
______
Local accommodations: nearest motel ______ ______ miles
Restaurants ______
Nearest hospital ______ Phone ______
Rental cars and vans available ______

Plant Operation and Process Description

Description of process ______
______
Description of control equipment ______
______

Schematic Drawing of Process Operation (Note location of sampling)

Sites and control equipment:

	Sampling sites	Anticipated constituents of stack gas
1.	______	______
2.	______	______
3.	______	______
4.	______	______
5.	______	______

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Process fuel type(s) ________________ **Feed rate** ________________

Process raw material(s) ________________ **Consumption rate(s)** ________________

Process production rate(s) ________________

Samples to be taken of: ________________

Plant operation: Continuous ________________ **Batch** ________________

Shift changes and breaks ________________

Plant facilities: Entrance requirements __________ **Food** __________ **Restrooms** __________

First aid __________ **Safety equipment** __________ **Compressed air source** __________

Laboratory ________________ **Equipment available** ________________

Reagents ________________ **Ice** ________________

Sampling Site and Stack Information

Sampling site	Type Pollutant emissions	Duct dimensions	Duct construction material	No. of sample ports	Port dimension	Diameters straight run to ports	Duct gas temp. °F	Duct gas velocity ft /sec	Average Δp in. H_2O in duct	% Δp in gas	Stack pressure in. Hg

Sketch of duct to be sampled with port locations and all dimensions

Sketch of sampling site including all dimensions

Access to work area

Work area (locate electrical outlets)

Electrical outlets available

1. **Voltage** ft
2. **Extension cords needed,**
3. **Adapters**

Recommended modifications to sampling site

Sampling method suggested **Nozzles**

Equipment needed: Sample probe length **Vertical**

Sample case: Horizontal traverse

Glassware **Sample case: Horizontal traverse** **Filter assemblies**

No. of needed sample cases **Meter consoles** **Probes**

Special equipment:

Reagents needed

Safety at Site

Condition description	Sampling site(s) general	Ladders	Scaffolds	Platforms	Lighting	Ventilation	Chemical hazard protection	Warning system
Good								
Adequate								
Poor								
Intolerable								

Personnel Safety Equipment

Item	Safety glasses	Full face shields	Hard hats	Safety shoes	Safety belts	Hearing protection	Respiratory equipment			Fire extinguishers	Chemical protection garments	Heat protecting garments	Asbestos aprons, gloves
							Purifying type	Self contained	Air supplied				
Needed at site													
Available at plant													
Must be brought by sample team													

Description of additional safety equipment recommended: ____________________

____

____

____

Comments: ____________________

____

METER CONSOLE CALIBRATION

Name________________________________ Date ________________________________

Console no. ______ Dry gas meter no. ______ Dry gas meter correction factor ______

Wet test meter no.____________________ Correction factor____________________

Barometric pressure, P_b__________ in. Hg Previous calibration and date__________

Orifice manometer setting, ΔH, in. H_2O	Gas volume wet test meter V_w, ft^3	Gas volume dry gas meter V_d, ft^3	Temperature				Time θ min	γ	$\Delta H_@$
			Wet test	Dry gas meter					
			Meter t_w, °F	Inlet t_{di}, °F	Outlet t_{do}, °F	Average t_d, °F			
0.5	5								
1.0	5								
2.0	10								
4.0	10								
6.0	10								
8.0	10								
						Average			

Calculations

ΔH	$\frac{\Delta H}{13.6}$	γ	$\Delta H_@$
		$\frac{V_w P_b (t_d + 460)}{V_d \left(P_b + \frac{\Delta H}{13.6}\right)(t_w + 460)}$	$\frac{0.0317\ \Delta H}{P_b(t_d + 460)} \left[\frac{(t_w + 460)\theta}{V_w}\right]^2$
0.5	0.0368		
1.0	0.0737		
2.0	0.147		
4.0	0.294		
6.0	0.431		
8.0	0.588		

γ = Ratio of accuracy of wet test meter to dry test meter. Tolerance = ± 0.02.

$\Delta H_@$ = Orifice pressure differential that gives 0.75 cfm of air at 68°F and 29.92 inches of mercury, in. H_2O. Tolerance = ± 0.15 inches.

Orifice $\Delta H_@$ should fall between 1.59 - 2.09 inches, or modification may be necessary for some sampling situations.

Form for meter console calibration

NOZZLE CALIBRATION

Date________________________ Calibrated by________________________

Nozzle identification #	D_1, in.	D_2, in.	D_3, in.	ΔD, in.	D_{avg}

where:

$D_{1,2,3,}$ = nozzle diameter measured on a different diameter, in. Tolerance = measure within 0.001 in.

ΔD = maximum difference in any two measurements, in. Tolerance = 0.004 in.

D_{avg} = average of D_1, D_2, and D_3.

Nozzle calibration data.

TEMPERATURE CALIBRATION

Name ______________________ Date ______________________

Barometric Pressure______________________ Land Elevation______________________

ICE BATH

Hg in Glass Thermometer Temperature				Corrected Hg in Glass Temperature				Temperature Device______________ Identification No.______________ Temperature			
°C	°K	°F	°R	°C	°K	°F	°R	°C	°K	°F	°R

BOILING WATER BATH

Hg in Glass Temperature				Corrected Temperature				Device ______________ No. ______________			
°C	°K	°F	°R	°C	°K	°F	°R	°C	°K	°F	°R

MINERAL OIL BATH

Point	Hg in Glass Temperature				Corrected Temperature				Device__________ No.__________			
	°C	°K	°F	°R	°C	°K	°F	°R	°C	°K	°F	°R
1												
2												
3												
4												

Form for temperature calibration.

Method 1—Sample and Velocity Traverses for Stationary Sources
Sample Site Selection and Minimum Number of Traverse Points

Plant ____________________ **Location** ____________________ **Date** ____________________

Sampling location ____

Sample team operator(s) ____

Sketch of stack geometry (including distances from sample site to any disturbances)

Interior duct cross-section dimension ______________ **ft**

Sampling port diameter ______________ **in.**

Sampling port nipple length ______________ **in.**

Stack cross-sectional area ______________ **ft^2**

Sampling site: diameter downstream of disturbance ____________ **Diameters upstream** ____________

Minimum number of sampling points ____________ **Individual point sample time** ____________

Total test time ______________________________

Comments:

Sketch of Stack Cross-Section Showing Sample Ports and all Dimensions

Sample point number	Circular stack % diameter	Distance from sample port opening in.
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.		
12.		

Particulate Field Data

Very Important—Fill in all Blanks

Plant ______
Run no. ______
Location ______
Date ______
Operator ______
Sample box no. ______
Meter box no. ______
Nomograph ID no. ______
Orsat no. ____ Date rebuilt ____
Fyrite no. ____ Date rebuilt ____

C_p ______
$\Delta H_@$ ______
P_m, in. Hg ______
P_s, in. Hg ______
B_{ws} (assumed) ______
M_d ______
M_s ______
T_m, °R ______
T_s, °R ______
$\Delta p_{avg.}$, in. H_2O ______

Test start time ______
Stop time ______
D_n calculated (in.) ______
D_n, used (in.) ______
Ambient temp., °F ______
Bar. pressure, in. Hg ______
Heater box setting, °F ______
Probe heater setting, °F ______
Average ΔH ______
Leak rate@15 in. Hg Pre-test ______ Post-test ______

Point	Clock time (min)	Dry gas meter CF	Pitot in H_2O Δp	Orifice ΔH in H_2O		Dry gas temp. °F		Pump vacuum in. Hg gauge	Box temp. °F	Impinger temp. °F	Stack press. in. Hg	Stack temp. °F	Fyrite %CO_2
				Desired	Actual	Inlet	Outlet						

Comments: ______

______

Test observers: ______ ______

continued

Point	Clock time (min)	Dry gas meter CF	Pitot in H_2O Δp	Orifice ΔH in H_2O		Dry gas temp. °F		Pump vacuum in. Hg gauge	Box temp. °F	Impinger temp. °F	Stack press. in. Hg	Stack temp. °F	Fyrite $\%CO_2$
				Desired	Actual	Inlet	Outlet						

Comments: ____

____

Test observers: ______________________ ______________________

continued

Laboratory Analysis Data Particulate Source Sample

Analysis date(s) ____________ **Analytical chemist** ____________
Plant sampled ____________ **Location** ____________
Sampling location ____________ **Sampling date(s)** ____________
Sample run no. ____________ **Sampling case no.** ____________
Sample labels: H_20 ________ **Silica gel** ________ **Filter** ________ **Probe** ________
Impinger rinse ________ **Dry particulate** ________ **Other** ________
Analysis performed ____________
Reference method ____________ **Analytical sample temp.** ____________
Comments: ____________
____
____

Moisture Data
Final volume H_20 in impingers ________ml
Initial volume H_20 in impingers ________ml
Volume H_20 condensed ________ml

Final weight silica gel ________gm
Initial weight silica gel ________gm

Total Moisture
H_20 Condensed ________ml

H_20 Absorbed ________gm

H_20 Total ________ml

Particulate Data
CH_3-CH_2-O-CH_2-CH_3/ $CHCl_3$ extract
Flask no. ________
Final weight ________mg
Initial weight ________mg
Organic fraction ________mg

Total Particulate Sampled
Organic fraction ________mg
Inorganic fraction ________mg
Front half particulates ________mg

Extracted H_20 Flask No. ________
Final weight ________mg
Initial weight ________mg
Inorganic fraction ________mg

Filter Flask No. ________
Final weight ________mg
Initial weight ________mg
Filter and particulates ________mg
Filter no. ____ **Tare weight** ____mg
Particulates ________mg
Dry particulates and probe ________mg
Front half particulates ________mg

Total Particulates
Run No. ____________

________mg

Orsat Field Data

Orsat identification no. ______________ **Date reagents added** ______________

Checked by ______________

Plant location ______________ **Sampling date** ______________

Operator(s) ______________

Sampling location ______________ **Average fyrite CO_2** ______________

Moisture content of stack gas (B_{ws}) ______________ **Fuel used** ______________

Fuel feed rate ______________ **Combustion source description** ______________

Process production rate ______________ **Steam production rate** ______________

Comments: ______________

____

Test no.	Sample time		Analysis time	Burette readings		
	Start	Stop		CO_2	O_2	CO

Component	Mole fraction = %composition
CO_2	
$O_2 - CO_2$	
$CO - O_2$	
$100 - CO = N_2$	

Dry molecular weight of stack gas $(M_d) = \Sigma M_x B_x$

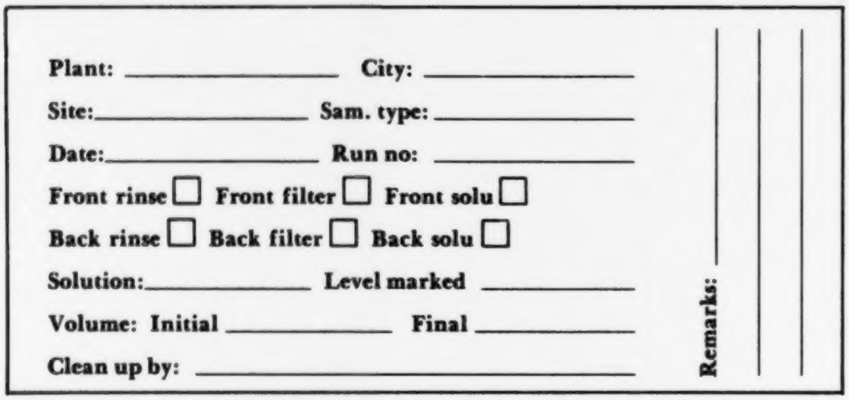
$M_d = .44\ (\_\_\%CO_2) + .32\ (\_\_\%O_2) + .28\ (\_\_\%CO) + .28\ (\_\_\%N_2) = \_\_$ gm/m

Wet molecular weight of stack gas $(M_s) = M_d(1 - B_{ws}) + 18\text{gm/m}(B_{ws})$

$M_s = (\_\_\text{gm/m})\ (1 - \_\_) + 18\text{gm/m}\ (\_\_) = \_\_$ gm/m

$$\%\ \text{Excess air in the duct}\ (\%EA) = \left[\frac{\%O_2 - 0.5(\%CO)}{(0.264)(\%N_2) - (\%O_2) + 0.5(\%CO)}\right] \times 100$$

$$\%\ EA = \left[\frac{(\_\_\%O_2) - 0.5(\_\_\%CO)}{(0.264)(\_\_\%N_2) - (\_\_\%O_2) + 0.5(\_\_\%CO)}\right] \times 100 = \_\_\_\_\%$$



Plant: ____________ **City:** ____________

Site: ____________ **Sam. type:** ____________

Date: ____________ **Run no:** ____________

Front rinse ☐ **Front filter** ☐ **Front solu** ☐

Back rinse ☐ **Back filter** ☐ **Back solu** ☐

Solution: ____________ **Level marked** ____________

Volume: Initial ____________ **Final** ____________

Clean up by: ____________

Remarks: ____________

Example sample label

Appendix B

Source Sampling Calculations

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Source Sampling Calculations

This section presents the equations used for source sampling calculations. These equations are divided into two parts—equipment calibration, and source test calculations. Gaseous source test equations are included to aid the source sampler performing both particulate and gaseous emissions tests. The purpose of the section is to give the reader a quick reference to necessary mathematical expressions used in source testing experiments.

EQUIPMENT CALIBRATION EQUATIONS

Stausscheibe (Type S) Pitot Tube Calibration

Calibration Coefficient (C_p)

(Eq. 6-1)
$$C_{p(s)} = C_{p(std)} \sqrt{\frac{\Delta p_{std}}{\Delta p_s}}$$

Deviation from Average C_p (Leg A or B of Type S tube)

(Eq. 6-2)
$$Deviation = C_{p(std)} - C_p$$

Average deviation from the mean δ (Leg A or B)

(Eq. 6-3)
$$\delta = \sum_{1}^{3} \frac{|C_{p(s)} - \bar{C}_{p(A \text{ or } B)}|}{3}$$

Sampling Probe Calibration Developed by Experiment and Graphed for Each Probe Length

Test Meter Calibration Using Spirometer

Spirometer volume (temperature and pressure correction not necessary for ambient conditions)

(Eq. 6-4) $[Spirometer\ displacement\ (cm)] \times [liters/cm] = liters\ volume$

Convert liters to cubic feet (ft^3)

Test Meter Correction Factor

(Eq. 6-5)
$$\frac{Spirometer\ Standard\ ft^3}{Test\ meter\ ft^3} = Test\ meter\ correction\ factor$$

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Correct Volume

(Eq. 6-6) [*Test meter volume*] × [*Test meter correction factor*] = *correct volume*

Orifice Meter Calibration Using Test Meter

Test meter volumetric flowrate (Q_m) in cubic feet per minute

(Eq. 6-7) $Q_m = [\text{Test meter } (V_f) - \text{Test Meter } V_i] \times [\text{Test meter correction factor}]$

where Q_m = *cubic feet per minute*

Proportionality Factor (K_m)

(Eq. 6-8)

$$K_m = Q_m \sqrt{\frac{P_m\, M_m}{T_m\, \Delta H}}$$

Orifice meter $\Delta H_@$

(Eq. 6-9) 1. *English units* $\Delta H_@ = \dfrac{0.9244}{K_m{}^2}$

where $Q_m = 0.75$ *cfm at* 68°F *and* 29.92 *in. Hg*

(Eq. 6-9) 2. *Metric units* $\Delta H_@ = \dfrac{0.3306}{K_m{}^2}$

where $Q_m = 0.021$ m^3/min *at* 760 *mm Hg and* 20°C

Sampling Meter Console Calibration

Ratio of the accuracy of Console Gas Meter Calibration Test Meter (γ).
Tolerance 1 ± 0.02

(Eq. 6-10)

$$\gamma = \frac{V_T\, T_m\, P_b}{V_m\, T_t \left(P_b + \dfrac{\Delta H}{13.6}\right)}$$

Meter Console Orifice Meter Calibration ($\Delta H_@$)

(Eq. 6-11) 1.

$$\Delta H_@ = \frac{K\, \Delta H}{P_b\, T_m} \left[\frac{T_T \theta}{V_T}\right]^2$$

where $K = 0.0317$ *English units*
$= 0.0012$ *metric units*

(Eq. 6-12) 2.

$$\Delta H_@ = \frac{0.9244}{\bar{K}_m{}^2}$$

Source Sampling Nomograph Calibration

Isokinetic ΔH Equation

(Eq. 6-13)

$$\text{Isokinetic } \Delta H = 846.72\, D_n^4\, \Delta H_@\, C_p^2\, \frac{T_m P_s}{T_s P_m}\, (1 - B_{ws})^2 \left(\frac{M_d}{M_s}\right) (\Delta p)$$

English units

Sampling Nozzle Equation

(Eq. 6-14)

$$D_n = \sqrt{\frac{0.0358\ Q_m\ P_m}{T_m\ C_p\,(1 - B_{ws})} \sqrt{\frac{T_s\ M_s}{P_s\ (\overline{\Delta p})}}}$$

English units

Adjusted C-Factor (C_p)

(Eq. 6-15)

$$C\text{-}Factor_{adjusted} = C_{factor} \left[\frac{C_p}{0.85}\right]^2$$

Adjusted C-Factor ($M_d \neq 29$)

(Eq. 6-15)

$$C\text{-}Factor_{adjusted} = C_{factor}\, \frac{1 - B_{ws} + 18\, B_{ws}/29}{1 - B_{ws} + 18 B_{ws}/M_d}$$

SOURCE SAMPLING CALCULATIONS

Method 1—Site Selection

Equal Area Equation (circular ducts)

(Eq. 6-16)

$$P = 50 \left[1 - \sqrt{\frac{2j - 1}{2n}}\right]$$

Equivalent Diameter for a Rectangular Duct

(Eq. 6-17)

$$D_E = \frac{2(length)\ (width)}{length + width}$$

Method 2—Gas Velocity and Volumetric Flow Rate

Average Stack Gas Velocity

(Eq. 6-18)

$$\bar{v}_s = K_p C_p \sqrt{\frac{T_s}{P_s M_s}} \left(\sqrt{\Delta p}\right)_{average}$$

Average Dry Stack Gas Volumetric Flow Rate at Standard Conditions ($\bar{Q}_s$)

(Eq. 6-19)

$$\bar{Q}_s = 3600\ (1 - B_{ws}) \bar{v}_s A_s \left[\frac{T_{std}}{P_{std}}\right] \frac{P_s}{T_s}$$

Method 3—Orsat Analysis

Stack Gas Dry Molecular Weight

(Eq. 6-20) $M_d = \Sigma M_x B_x = 0.44(\%CO_2) + 0.32(\%0_2) + 0.28(\%N_2 + \%CO)$

Stack Gas Wet Molecular Weight

(Eq. 6-21) $M_s = M_d(1 - B_{ws}) + 18\ B_{ws}$

Percent Excess Air (%EA)

(Eq. 6-22) $$\%EA = \frac{(\%0_2) - 0.05(\%C0)}{0.264\ (\%N_2) - (\%0_2) + 0.5(\%C0)} \times 100$$

Method 4—Reference Moisture Content of a Stack Gas

Volume Water Vapor Condensed at Standard Conditions (V_{wc})

(Eq. 6-23) $$V_{wc} = \frac{(ml\ H_2O)\rho_w\ R\ T_{std}}{P_{std}\ M_w} = K_1\ (V_f - V_i)$$

where $K_1 = 0.001333\ m^3/ml$ *for metric units*
$= 0.04707\ ft.^3/ml$ *for English units*

Silica Gel

(Eq. 6-24) $K_2 = (W_f - W_i) = V_{w\ SG}$

where $K_2 = 0.001335\ m^3/gm$ *for metric units*
$= 0.04715\ ft.^3/gm$ *for English units*

Gas Volume at Standard Conditions

(Eq. 6-25) $$V_{m(std)} = V_m Y_m \left(\frac{T_{std}}{P_{std}}\right) \left(\frac{P_b + \frac{\Delta H}{13.6}}{T_m}\right)$$

Moisture Content

(Eq. 6-26) $$B_{ws} = \frac{V_{wc} + V_{w\ SG}}{V_{wc} + V_{w\ SG} + V_{m(std)}}$$

Method 5—Particulate Emissions Testing

Dry Gas Volume Metered at Standard Conditions

Leak Rate Adjustment

(Eq. 6-27) $$V_m = [V_m - (L_1 - L_a)\theta - \sum_{i=2}^{N} (L_i - L_a)\theta_i - (L_p - L_a)\theta_p]$$

Standard Dry Volume at Sampling Meter

(Eq. 6-28)
$$V_{m(std)} = V_m Y_m \left(\frac{T_{std}}{P_{std}}\right) \left(\frac{P_b + \frac{\Delta H}{13.6}}{T_m}\right)$$

Isokinetic Variation

Raw Data

(Eq. 6-29)
$$\%I = \frac{100\ T_s\ [K_3 V_{lc} + (V_m / T_m)\ \ (P_b + \Delta H/13.6)]}{60\ \theta_s\ v_s P_s A_n}$$

where
$$K_3 = 0.003454\ \frac{mm\ Hg\ m^3}{ml\ °K}$$

$$= 0.002669\ \frac{in.\ Hg\ ft.^3}{ml\ °R}$$

Note: This equation includes a correction for the pressure differential across the dry gas meter measured by the orifice meter—average sampling run ΔH readings.

Intermediate Data

(Eq. 6-30)
$$\%I = 100 \frac{T_s\ V_{m(std)}\ P_{std}}{T_{std}\ \bar{v}_s\ \vartheta\ A_n\ P_s\ 60\,(1 - B_{ws})}$$

Method 8—Sulfuric Acid Mist and Sulfur Dioxide Emissions Testing

Dry volume metered at standard conditions (see equations in previous sections of this outline)

Sulfur Dioxide concentration

(Eq. 6-31)
$$c_{SO} = K_3 \frac{N(V_t - V_{tb}) \left(\frac{V_{solution}}{V_{aliquot}}\right)}{V_{m(std)}}$$

where
$K_3 = 0.03203$ *g/meq for metric units*
$= 7.061 \times 10^{-5}$ *lb/meq for English units*

Sulfuric acid mist (including sulfur trioxide) concentration

(Eq. 6-32)
$$c_{H_2SO_4} = K_2 \frac{N(V_t - V_{tb}) \left(\frac{V_{solution}}{V_{aliquot}}\right)}{V_{m(std)}}$$

where $K_2 = 0.04904\ g/meq$ *for metric units*

$= 1.08 \times 10^{-4}\ lb/meq$ *for English units*

Isokinetic Variation

Raw Data

(Eq. 6-33)
$$\%I = 100\,\frac{T_s\,[K_4 V_{lc} + (V_m/Tm)(P_b + \Delta H/13.6)]}{60\theta A_n v_s P_s}$$

where $K_4 = 0.003464\ mm\ Hg - m^3/ml - {}^\circ K$

$= 0.002676\ in\ Hg - ft^3/ml - {}^\circ R$

Concentration Correction Equations

Concentration Correction to 12% CO_2

(Eq. 6-34)
$$c_{s12} = c_s \left[\frac{12}{\%CO_2}\right]$$

Concentration Correction to 50% Excess Air Concentration

(Eq. 6-35)
$$c_{s50} = \left[\frac{100 + \%EA}{150}\right]$$

Correction to 50% Excess Air Using Raw Orsat Data

(Eq. 6-36)
$$c_{s50} = \frac{c_s}{1 - \left[\dfrac{(1.5)(\%O_2) - (0.133)(\%N_2) - 0.75(\%CO)}{21}\right]}$$

F-Factor Equations

F_c Factor

(Eq. 6-37)
$$E = F_c\, c_s \left(\frac{100}{\%CO_2}\right)$$

Used when measuring c_s and CO_2 on a wet or dry basis.

F_d Factor

When measuring O_{2d} and c_s on a dry basis

(Eq. 6-38)
$$E = F_d\, c_{sd} \left[\frac{20.9}{20.9 - \%O_{2d}}\right]$$

When measuring O_{2d} and c_s on a wet basis

(Eq. 6-39)
$$E = F_d\, c_{ws} \left[\frac{20.9}{20.9(1 - B_{ws}) - \dfrac{\%O_{2w}}{1 - B_{ws}}}\right]$$

F_w Factor

- When measuring c_s and O_2 on a wet basis
- B_{wa} = moisture content of ambient air
- Cannot be used after a wet scrubber

(Eq. 6-40) $$E = F_w \, c_{ws} \left[\frac{20.9}{20.9(1 - B_{wa}) - \%O_{2w}} \right]$$

F_o Factor

1. Miscellaneous factor for checking Orsat data

(Eq. 6-41) $$F_o = \frac{20.9}{100} \frac{F_d}{F_c} = \frac{20.9 - \%O_{2d}}{\%CO_{2d}} \quad \left(\begin{array}{c} O_2 \text{ and } CO_2 \text{ measured} \\ \text{on dry basis} \end{array} \right)$$

Opacity Equations

%Opacity

(Eq. 6-42) $$\%Opacity = 100 - \%\ Transmittance$$

Optical Density

(Eq. 6-43) $$Optical\ Density = log_{10} \left[\frac{1}{1 - Opacity} \right]$$

(Eq. 6-44) $$Optical\ Density = log_{10} \left[\frac{1}{Transmittance} \right]$$

Transmittance

(Eq. 6-45) $$Transmittance = e^{-naql}$$

Plume Opacity Correction

(Eq. 6-46) $$log(1 - O_1) = (L_1/L_2)\ log(1 - O_2)$$

Appendix C

Problems

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PROBLEMS WITH SOLUTIONS

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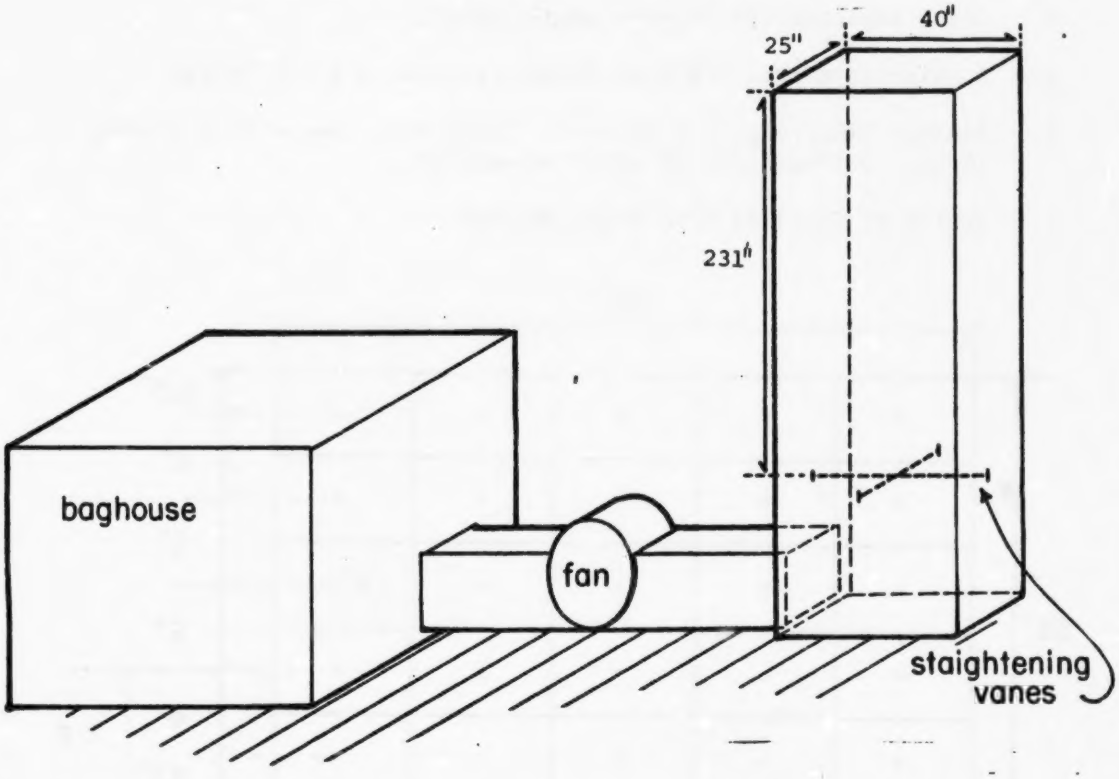
SAMPLE SITE SELECTION

Problem 1.

The diagram below is a sketch of a duct to be sampled using the EPA Method 5 Sampling Train. Using Method 1 guidelines calculate the equivalent diameter of the duct, select the best sampling site, sample port entry number, and sampling point number (the plant will weld on threaded 3" diameter, 6" long steel pipe nipples as Sample ports. Determine the sampling time at each test point and total test time. Sketch out all work with dimensions.



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Note: This is an actual stack encountered at an asphalt batch manufacturing operation. The problem requires the best possible application of Method 1 guidelines. This is a new stationary source and new source performance standards require total test time $\geq$ 60 minutes and minimum time/sample point $\geq$ 2 minutes.

1. Equivalent Diameter

$$D_E = 2\,\frac{25'' \times 40''}{25'' + 40''} = 30.8''$$

2. $$\frac{\text{231" total duct dimension to exit}}{D_E = 30.8} = \text{7.5 diameter total}$$

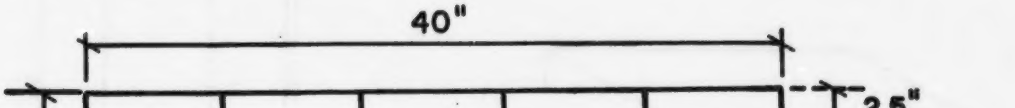
3. Sampling site selection is best at 6 diameters downstream and 1.5 upstream.

4. Chart indicates 24 or more sample points.

5. A balanced matrix (FR page 41756) requires a 5 x 5 layout.

6. Minimum time/point 2.5 minutes. total test time = 62.5 minutes. (Note: 3 minutes/point would be easiest).

7. Sketch of Sampling Site Cross-section.



Sample Point	Distance from 6" Long Nipple Opening
1	2.5" + 6" = 8.5"
2	7.5" + 6" = 13.5"
3	12.5" + 6" = 18.5"
4	17.5" + 6" = 23.5"
5	22.5" + 6" = 28.5"

Problem 2.

An "S" type pitot tube was used with an assumed Cp = 0.85 for performing a source test. Laboratory calibration of the tube showed that for the conditions at the source the actual Cp = 0.80. Explain all the ramifications of this error given the data below.

B_{ws} = 7%

M_s = 30.0lb/lbmole

P_s = 30.04 in. Hg

Δp = 1.2 in H_2O

Θ = 60 minutes

T_s°R = 700

$V_{m(std)}$ = 45.25 SCF

Particulate Concentration = .2 grains/DSCF

A_s = 20 ft.^{2}

A. Velocity

1. $C_p = 0.85$

$$v_s = 85.49\,(0.85)\left[\frac{700\,(1.2)}{30.04(30.0)}\right]^{\frac{1}{2}} = 70.16 \text{ ft./sec}$$

2. $C_p = 0.80$

$$v_s = 85.4\ \ (.8)\left[\frac{700\,(1.2)}{30.04\,(30.0)}\right]^{\frac{1}{2}} = 66.03 \text{ ft./sec}$$

5.88% error

B. Volumetric Flow Rate

1. $C_p = 0.85$

$$Q_s = 3600\,(1-0.07)(70.16)(20)(17.65)\left(\frac{30.04}{700}\right) = 3{,}558{,}000 \text{ SCFH}$$

2. $C_p = 0.80$

$$Q_s = 3600\,(1-0.007)(66.03)(20)(17.65)\left(\frac{30.04}{700}\right) = 3{,}348{,}000 \text{ SCFH}$$

5.90% error

C. Isokinetic Flow Rate

1. Nozzle Velocity

   a. $C_p = 0.85$

      Nozzle velocity (v_n) > stack gas velocity

Overisokinetic

   b. $C_p = 0.80$ $v_n = v_s$ = isokinetic

2. Overisokinetic Condition

   a. Biased sample with small particles

   b. 0.2 gr/SCF < real concentration

Problem 3.

Stack Gas Velocity

An "S" type pitot tube with a $C_p = 0.84$ was used to take a stack gas velocity reading in an oil fired power plant duct. The circular duct had a diameter of 10ft. The Δp measured in the duct was 0.5 in. H_2O. The average stack gas temperature was 300°F. The wet molecular weight of the gas was 30.0 gm/mole. Moisture content was 6% H_2O. Absolute stack pressure was 30.0 in. Hg. Calculate the average gas velocity in feet/second. Calculate the volumetric flow rate in standard cubic feet/hour.

1. Average Stack Gas Velocity

a. $$v_s = K_p\, C_p \left[\frac{(T_s)\ \Delta p}{P_s\ \ M_s}\right]^{\frac{1}{2}}$$

b.

$$v_s = 85.49 \left[\frac{(760°)(0.5)}{(30.0)(30.0)}\right]^{\frac{1}{2}} (.84)^{\frac{1}{2}}$$

$$= 46.7 \text{ ft/sec}$$

2. Average Stack Gas Volumetric Flow Rate (Dry SCFH)

a. $$Q_s = 3600 \text{ sec./hr. } (1-B_{ws})(v_s)(\text{Area})\left[\frac{528°R}{T_s°R}\right] \frac{P_s}{29.92 \text{in. Hg.}}$$

b. $$Q_s = 3600 \text{ sec./hr. } (1-0.06)(46.7\text{ft./sec.})\ \pi\ (5\text{ft.})^2$$

$$\left[\frac{528°R}{760°R}\right] \frac{30.0\text{in.Hg.}}{29.92\text{in.Hg.}} = 8{,}646{,}000 \text{ SCFH}$$

What would be the volumetric flow rate of the stack gas exiting the duct in the above problem in actual cubic feet/hour at stack conditions?

a. $Q_a = (\bar{v}_s \text{ ft./sec.}) \times (\text{Area}) \times 3600 \text{ sec./hr.}$

b. $Q_a = (46.7 \text{ ft./sec.})\ \pi\ (5\text{ft.})^2 \times 3600 \text{ sec./hr.}$

$= 13{,}204{,}000$ ACFH

Problem 4.

Molecular Weight of a Stack Gas

An integrated bag sample of the stack gas in coal fired power plant duct was analyzed by orsat. The orsat indicated readings for CO_2 - 14.2; O_2 - 21.4; and CO - 21.4.* The moisture content of the stack gas was 7% H_2O vapor. What is the molecular weight of the gas?

1. Stack Gas Constituents

$CO_2 = 14.2\%$ by volume

$O_2 = 21.4 - 14.2 = 7.2\%$ by volume

$CO = 21.4 - 21.4 = 0\%$

$N_2 = 100 - 21.4 = 78.6\%$ by volume

$H_2O = 7\%$

2. Dry Molecular Weight of Gas

$M \text{ dry} = \Sigma\ M_x\ B_x$ $\quad M_x$ = Molecular weight component $\quad B_x$ = Mole fraction expressed as % by volume

*Note: Orsat analysis readings indicate a direct % reading for CO_2 and additive readings for O_2 and CO. Therefore in the problem above:

$CO_2 = 14.2\%$ by volume (read directly)

$O_2 = O_2 - CO_2 = 21.4 - 14.2 = 7.2\%$ by volume

$CO = O_2 - CO = 21.4 - 21.4 = 0\%$ CO by volume

$$M\ dry = 44lb/lb\text{-}mole(\%CO_2) + 32lb/lb\text{-}mole(\%O_2) + 28lb/lb\text{-}mole(\%CO)$$

$$+ 28lb/lb\text{-}mole(\%N_2)$$

$$=44(.142) +32(.072) +28(0) + 28(.786)$$

$$= 6.248 + 2.304 + 0 + 22.008$$

$$= 30.560lb/lb\text{-}mole$$

3. Wet Molecular Weight of Gas

$M_s = M\ dry\ (1-B_{ws}) + 18(B_{ws})$ B_{ws} = % H_2O vapor in stack gas

$$= 30.560lb/lb\text{-}mole\ (1-0.07) + 18lb/lb\text{-}mole\ (0.07)$$

$$= 28.421 + 1.26$$

$$= 29.681lb/lb\text{-}mole$$

Problem 5.

Moisture Content of a Stack Gas

Reference Method 4 for determination of the moisture content of a stack gas was completed at a coal fired power plant duct. From the following data calculate the % H_2O present in the stack gas.

$V_{metered}$ = 1.258 CF

Test Time = 20 minutes

t_m°F = 80

t_s°F = 250

P_m = 30.25 in. Hg.

H_2O Volume collected in the Impingers = 2.6 ml

H_2O Weight increase in Silica Gel = 2.4 fm.

1. Volume Metered at Standard Conditions.

$$V_{m(std)}^{*} = V_m \left[\frac{T_{std}}{P_{std}}\right] \frac{P_m}{T_m}$$

$$V_{m(std)} = 1.258\ CF \left[\frac{528°R}{29.92 in.Hg.}\right] \frac{30.25\ in.Hg.}{540°R} = 1.244\ SCF$$

2. H_2O Condensed Converted to Standard Cubic Volume of H_2O Vapor

   a. Impinger (V_{wc})

   2.6 ml X 0.04707 SCF/ml = .12238 SCF

   b. Silica Gel (V_{sg})

   2.4 m. X 0.04715 SCF/ml = .11316

3. (B_{ws}) Moisture Content

$$B_{ws} = \frac{V_{wc} + V_{sg}}{V_{wc} + V_{sg} + V_{m(std)}} \times 100 = \frac{0.236}{0.236 + 1.244} = 15.95\%$$

Problem 6.

Percent Isokinetic

A 1 hour long source test conducted at an oil fired steam generation facility provided the following information:

Average Stack Temperature = 300°F

Average Stack Gas Velocity = 50.0 ft./sec.

Volume Sampled at Meter Conditions = 40 cubic feet

Average Temperature at the Meter = 70°F

Static Pressure in the Stack = +0.2 in. H_2O

Barometric Pressure = 30.26 in. Hg.

Average Pressure Differential Across the Orifice = 1.5 in. H_2O

*Note: V_m = Volume at meter X Dry Gas Meter Correction Factor (DGMCF)

In this example assume DGMCF = 1

H_2O Collected in the impingers = 100 ml

Sampling Nozzle Diameter = 0.250 inches

What is the % isokinetic for this source test?

a. % Isokinetic from Raw Data

$$\%I = 100 \text{ X } \frac{T_s{}^\circ R \left[K(\text{Volume } H_2O) + (V_m/T_m)\left(P_b + \frac{\Delta H}{13.6}\right)\right]}{\bar{v}_s \; 60\text{sec./min.} \; (\theta\text{min.}) \; P_s \; (\text{Nozzle Area})}$$

b. % I

$$\%I = 100 \text{ X } \frac{760^\circ R \left[\left(0.00267 \frac{\text{in.Hg -ft.}^3}{\text{ml - }^\circ R} \right)(100\text{ml}) + \frac{40\text{ft.}^3}{530\ ^\circ R}\left(30.26\text{in.Hg} + \frac{1.5\text{in. } H_2O}{13.6}\right)\right]}{(50\text{ft./sec.})60\text{sec./min.}(60\text{min.})\left(30.26\text{in. Hg} + \frac{0.2\text{in.}H_2O}{13.6}\right)(0.0003408 \text{ ft}^2)}$$

The 1 hour second stack test at the same facility gave intermediate data as follows:

% H_2O in Stack Gas = 6.5

Volume metered at Standard Conditions = 38.8DSCF

Static Pressure in the Stack = 0.25 in. H_2O

Barometric Pressure = 30.30 in. Hg.

Nozzle Diameter = 0.248 inches

Average Velocity = 49.8 ft./sec.

Average Stack Temperature = 296°F

What is the percent isokinetic for this source test?

$$\% \text{ I} = 100 \times \frac{T_s V_{m(std)} P_{std}}{T_{std} \bar{v}_s P_s \; \theta\text{min.}(60\text{sec./min.})(\text{Nozzle Area})(1-B_{ws})}$$

b. % Isokinetic

$$\% I = 100 \times \frac{760°R\ (38.8 ft.^3)\ (29.92 in.\ Hg.)}{(528°R)(30.30 + \frac{0.25}{13.6})(49.8 ft./sec.)(1-0.06)(3600)(0.0003352 ft.^2)}$$

$$= 97.05$$

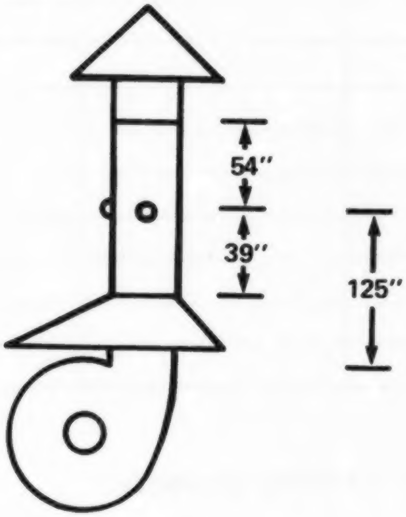
ADDITIONAL PROBLEMS

ADDITIONAL PROBLEMS

BACKGROUND

During a recent presite survey at a wood waste boiler in Pactolus, North Carolina, the following information was obtained concerning emission description and emission information from the exhaust of the boiler:

a) Sketch



b) Information

% Moisture in Stack Gas (B_{ws}): 7.0 %
Stack gas Temperature (t_s): 303°F
Average Δp: 0.15 " H_2O
C_p: 0.845
Orsat Data: CO_2: 14.2 %
O_2: 5.0 %
CO : 0.0 %
Absolute Stack Gas Pressure: 30.3 " Hg
Stack Diameter: 16"
Stack Configuration: Circular

PROBLEM 1.

With the assistance of Federal Register Method 1 as outlined in Vol. 42, No. 160, Aug. 18, 1977, complete the following table for a particulate traverse.

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TABLE #1

Sample Point Number	Circular Stack % Diameter	Distance From Sample Port Opening in.
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.		
12.		

PROBLEM 2. Determine the following parameters:

Average Stack Gas Velocity ($\overline{v}_s$): ft/sec
Average Stack Gas Volumetric Flow Rate ($\overline{Q}_s$): DSCFH
Actual Stack Gas Volumetric Flow Rate (Q_a): ACFH

PROBLEM 3. During a recent visit to a fertilizer plant, the following information was obtained concerning emissions from the drying operation:

Stack Temperature (t_s): 300°F
Per Cent Moisture in Flue Gas (B_{ws}): 12%
Per Cent O_2 in Flue Gas: 2%
Per Cent CO_2 in Flue Gas: 17%
Per Cent CO in Flue Gas: nil
Barometric Pressure: 30.1 " Hg
Pressure of Stack: -15.0 " H_2O
C_p: 0.842
Δp: 2.5 " H_2O

From the above information, determine the average stack gas velocity ($\overline{v}_s$).

Problem 4.

Given the following calculate (B_{ws}) moisture content of the stack gas

H_2O collected in the impingers = 75 ml

H_2O collected in the silica gel = 25 gms

Volume metered = 40.20 cubic feet

P_m = 30.0 in. Hg

t_m = 100°F

Answers:

$V_{m_{std}}$ = 37.99 SCF

$V_{wc_{std}}$ = 3.54ft^3

$V_{sg_{std}}$ = 1.18ft^3

B_{ws} = 11.03%

Problem 5.

Given the following information determine the "S" type Pitot tube Cp, Dry Molecular Weight of the Stack Gas (M_d) and Wet Molecular Weight (M_s), Stack Gas Velocity, and Volumetric Flow Rate.

Pitot Tube Data:

$C_{p_{std}}$ = 0.99

Δp_{std} = 0.31 in. H_2O

Δp_{Test} = 0.42 in. H_2O

Orsat Analysis

CO_2 = 13%

O_2 = 6%

CO = 1%

N_2 = 79%

Stack Data

$(t_s)_{avg}$ = 350°F

(Δp_{avg}) = 0.59 in. H_2O Note: this equals $(\sqrt{\Delta p_{ave}})^2$

P_s = 29.00 in. Hg

B_{ws} = 10%

A_s = 1200 ft.^{2}

Answers:

C_p = 0.851

M_d = 30.04lb/lb-mole

M_s = 28.84lb/lb-mole

v_s = 54.98 ft/sec

Q_s = 1.35 x 10^8 dscfh

Problem 6.

Using the given information calculate the Concentration of Particulate in the Gas Stream (c_s), Moisture Content (B_{ws}), and % Isokinetic for the test

Volume metered = 50 ft^3

P_v = 29.5 in. Hg.

ΔH = 1.5 in. H_2O

t_m = 100°F

t_s = 300°F

Θ = 60 minutes

v_s = 48.0 ft./sec.

P_s = 29.00 in. Hg.

A_n = 0.0003408 $ft.^2$

Total H_2O collected (condenser and silica) = 100 ml

Particulate Catch (M_n) = 100 mg

Answers:

$V_{m_{std}}$ = 46.64 $ft.^3$

B_{ws} = 9.186%

c_s = 0.033gr./DSCF

%I = 129.7%